The incorporation of lime and NPK fertilizer on shallot production in peat soil

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Abstract. High acidity level and low nutrient availability are the most challenging factors of shallot production in peat soils. The purpose of this study was to find out the best lime material and the level of NPK fertilizer on shallot production in peat soil in Central Borneo, Indonesia. The experiment used was a Split Plot Design with three replications. The main plot was three types of lime material: 3 t ha⁻¹ dolomite, 3 t ha⁻¹ agriculture limestone and 1.5 t ha⁻¹ calcium hydroxide. The subplots were ten combinations of NPK fertilizers. The results showed that lime materials and doses of NPK fertilizer had a significant effect on shallot growth and yield. Hydrated lime doses 1.5 t ha⁻¹ and NPK fertilizer dose 100 kg N ha⁻¹, 100 kg P₂O₅ ha⁻¹ and 100 kg K₂O ha⁻¹ gave the highest bulb yield (7 t ha⁻¹) compared to other trials. However, this bulb yield was lower compared to different adaptive cultivars from previous studies. Further experiments using higher levels of lime and adapted varieties are necessary to get the optimum bulb yield.

1. Introduction
Shallot (Allium cepa Aggregatum group, also known as Allium ascalonicum) is one of the essential vegetables in Indonesia that adapt well in many different areas, including in organic soils and peat soils [1]. One of the most challenging factors of shallot production in organic soil is the low pH. Soil pH drives nutrient availability, which involves plant growth and yield.

Acid soils have several limitations such as low of phosphorus and base cations availability and high concentration of aluminum and manganese that induce essential nutrient deficiency and acidic toxicity. The high concentration of exchangeable acidity (Al³⁺ and H⁺) blocks P absorption sites and impairs plant growth [2]. However, the high concentration of exchangeable Al³⁺ does not commonly occur in peat soils due to high concentration of organic materials that strongly adsorb Al³⁺ to R-COO⁻ sites and reduces the Al toxicity [3]. Nevertheless, the deficiency of essential nutrients remains. In Allium cepa, deficiency on phosphorus element decreases vegetative growth, bulb size and bulb yield [4].

The acidic soils also have low concentration of base cations (Ca²⁺, Mg²⁺, K⁺ and Na⁺) that inhibits the essential nutrient uptake and causes a nutrient deficiency. Several studies have been done to find out the best management practice of shallots in peat soils. It was reported that soil amelioration is one of the most important factors to increase shallot production in peat soils. For example, Hatta and Nugroho [5] reported that soil amelioration sea mud 56 t/ha increased the shallot production up to 25% from 10.9
t/ha to 13.6 t/ha and incorporation of the sea mud with manures increased the response [6]. In addition, the application of dolomite doses 9 t/ha increased the shallot bulb yield by 248% of those without dolomite [7]. All the soil ameliorations were allocated to improve soil pH. However, high dose of organic amendments makes it inefficient and inapplicable in the farmer’s fields. The most effective and efficient method to deal with the soil pH is by liming material application.

Liming materials become necessary to improve the soil properties and to achieve the optimum yield. However, the response of lime application in improvement of soil pH and crop yields varies on the type, method and rate of liming materials. Moreover, the limitation of essential nutrients, especially phosphorus and potassium, alters plant physiology that slows the rate of growth and decreases crop yield. Macronutrient fertilization is necessary to supply the nutrients and support the plant growth. To produce 15 t ha\(^{-1}\), shallots absorbed 110 kg ha\(^{-1}\) N, 30 kg P\(_2\)O\(_5\) ha\(^{-1}\), and 106 kg K\(_2\)O ha\(^{-1}\) [8]. A low uptake would give a low yield.

Despite many works of literature had reported the effect of lime materials on increasing pH and the impact of NPK fertilization on shallot growth and yield [8–11], there is still a gap of understanding in the effectiveness of liming materials and NPK fertilization in improving shallot bulb yield in peat soils in Borneo, Indonesia. Liming materials broadly used in Indonesia are dolomite and agriculture limestone. Other than those materials, hydrated lime or known as Kapur Bangunan or Kapur Padam also available at a reasonable price. This research aims to find out the best liming materials and NPK fertilizer rates on shallot production in Central Borneo’s peat soil, Indonesia.

2. Materials and methods

The research was conducted in Desa Kereng Bangkirai, Kecamatan Sebangau, Kota Palangkaraya, Central Borneo, Indonesia (2\(^{\circ}\)17'18'' S, 113\(^{\circ}\)53'20''), the altitude is 11 m above sea level. Climatic data were collected from Badan Meteorologi dan Geofisika (BMKG) Kota Palangkaraya. The monthly rainfall was 391 mm per month during the growing time, between April and June 2016, with a maximum of 444 mm in April and a minimum of 292 mm in May 2016. The mean temperature was 28.2°C with minimum temperature 23.1°C, and the maximum temperature was 34.8°C. The average of relative humidity was 84% with minimum relative humidity was 52%, and the maximum relative humidity was 98%. The average of atmospheric pressure was 1,013.3 Mb, the average wind velocity was 3.95 knots, and the average of the duration of sunshine was 58%. The type of soil is a shallow peat soil (the thickness of peat less than 1 m). The soil is very acid (pH\(_{\text{water}}=3.7\)), high in C-organic (C-org=55%), high in nitrogen (N=0.9%), low of phosphorus available (P-Bray-1=18 ppm), and high in potassium (K-Morgan=117 ppm).

In this study, we used a Split Plot Design with three replications. The main plot was three types of lime materials: (L1) 3t/ha dolomite; (L2) 3t/ha limestone agriculture and (L3) 1.5t/ha hydrated lime. The subplots were the levels of NPK fertilizer (N-P\(_2\)O\(_5\)-K\(_2\)O) on kg ha\(^{-1}\): (P1) 0-100-200; (P2) 150-100-200; (P3) 300-100-200; (P4) 50-0-200; (P5) 150-200-200; (P6) 150-300-200; (P7) 150-100-0; (P8) 150-100-100; (P9) 150-100-300; (P10) 150-100-400. All the lime materials and phosphorus fertilizer were incorporated at once after manual ploughing at one day before planting time. Nitrogen and potassium fertilizers were applied two times, 15 and 30 days after planting. The source of N was Calcium Ammonium Nitrate (25%N and 12% CaO), the source of P fertilizer was super phosphate-36 (36% P\(_2\)O\(_5\) or 16% P), and the source of K fertilizer was potassium chloride (60% K\(_2\)O or 50% K). In additions, all plots received 20 tons/ha chicken manure as a basic fertilizer, which was applied to the lime materials.

The shallot cultivar used was ‘Bima’ from Dinas Pertanian dan Peternakan Palangkaraya. The study was conducted in the field with three main plots \(\times\) 10 subplots \(\times\) 3 replications = 90 plot treatments. The size of the plot was 1x6 m\(^2\), and the plant spacing was 15 x 20 cm. There was approximately 168 plants/plot. The plot was a bed with a width of 100 cm, and the distance between beds was 50 cm. The height of the bed was 20-30 cm from the base.

After the shallot grown on the experimental plots, soil samples were taken in May 2016. One composite sample was taken at a depth of 0-20 cm from each treatment plot. For soil analysis purpose, the soil samples were oven-dried at 40°C (Memmert type UN 450) and sieved at 2 mm and 0.5 mm. Soil
In this experiment, liming and NPK fertilization reduced the C content altering soil acidity compared to other soil amendments. Dolomite doses 3 t ha\(^{-1}\) increased plant biomass was measured at four weeks after planting. Plant availability of nutrient ns=not significant; means presenting the same letter are not statistically different by DMRT at α=5%.

3. Results and discussion

3.1. Soil analysis

The application of lime reduces soil acidity and toxic ions and enhances nutrient mobility. The types of liming materials had a significant effect on improving soil pH (Table 1). The application of dolomite gave the lowest altering soil acidity compared to other soil amendments. Dolomite doses 3 t ha\(^{-1}\) increased the pH from 3.7 to 4.1; agriculture limestone doses 3 t ha\(^{-1}\) increased the pH from 3.7 to 4.3 and hydrated lime doses 1.5 t ha\(^{-1}\) increased the soil pH from 3.7 to 4.5. These findings similar to many previous studies that stated the application of liming materials, such as dolomite and agriculture limestone increased soil pH significantly [13–15].

The efficiency of liming materials on increasing soil pH depends on the calcium carbonate equivalence (CCE) and the particle size of the product. Dolomite has >100% of CCE, agriculture limestone has > 85% of CCE, and hydrated lime has > 110% CCE [16]. The high number of CCE in hydrated lime may explain the increment of the soil pH in this plot that higher than other lime materials, even though it had a smaller dose than the others.

Table 1. Soil analysis before and after the experiment.

| Treatments                      | pH (H\(_2\)O) | C (%) | N (%) | C/N | Bray1-P (ppm) | K-Morgan (ppm) |
|--------------------------------|--------------|-------|-------|-----|---------------|----------------|
| **Before Experiment**           |              |       |       |     |               |                |
| Peat Soil                      | 3.7          | 55    | 0.90  | 61  | 41            | 141            |
| **After Experiment**            |              |       |       |     |               |                |
| Liming materials:              |              |       |       |     |               |                |
| 3 t/ha Dolomite                | 4.1\(^{a}\)  | 41\(^{ns}\) | 1.19\(^{ns}\) | 34\(^{ns}\) | 313\(^{ns}\) | 685\(^{ns}\) |
| 3 t/ha Agriculture limestone   | 4.3\(^{ab}\) | 41    | 1.19  | 35  | 311           | 568            |
| 1.5 t/ha Hydrated lime         | 4.5\(^{a}\)  | 36    | 1.06  | 35  | 390           | 539            |
| NPK levels (N-P\(_2\)O\(_5\)-K\(_2\)O) |              |       |       |     |               |                |
| P1 (0-100-200)                 | 4.3\(^{ns}\) | 40    | 1.13  | 37  | 342           | 561            |
| P2 (150-100-200)                | 4.3          | 37    | 1.10  | 33  | 343           | 608            |
| P3 (300-100-200)                | 4.2          | 40    | 1.16  | 34  | 310           | 630            |
| P4 (150-0-200)                  | 4.3          | 42    | 1.06  | 39  | 285           | 718            |
| P5 (150-200-200)                | 4.1          | 40    | 1.06  | 38  | 354           | 610            |
| P6 (150-300-200)                | 4.3          | 36    | 1.11  | 32  | 388           | 496            |
| P7 (150-100-0)                  | 4.5          | 37    | 1.09  | 34  | 332           | 469            |
| P8 (150-100-100)                | 4.4          | 40    | 1.17  | 34  | 348           | 536            |
| P9 (150-100-300)                | 4.3          | 41    | 1.22  | 33  | 352           | 612            |
| P10 (150-100-400)               | 4.3          | 43    | 1.34  | 33  | 325           | 730            |

ns=not significant; means presenting the same letter are not statistically different by DMRT at α=5%.

Naturally, acidic soil has a low available P-soil and the application of NPK fertilizers increase the availability of nutrient. In this experiment, liming and NPK fertilization reduced the C-organic from 55% to 36-41% and increased the nitrogen content from 0.90% to 1.06-1.19%, P-Bray-1 from 18 to 124-
167 mg P/kg, and K-Morgan from 117 to 261-606 ppm (Table 1). The high amount of N, P and K in the soil after the experiment came from the chemical fertilizer (NPK), organic fertilizer (chicken manure) and the soil organic mineralization and decomposition.

The application of NPK fertilizer increased the concentration of N, Bray-P and K-Morgan significantly. These findings similar with Moore [17] who reported that the concentration of \( \text{NH}_4^+ \), \( \text{NO}_3^- \), dissolved organic nitrogen, phosphate and dissolved organic phosphorus in NPK-fertilized peat were significantly higher than control. Wang [18] reported that N fertilizer generally increased the N content of peat during the period when the fertilization applied. Furthermore, NPK fertilization also increases residue K in peatlands [11,18].

During the plant-cropping period, peat was decomposed and mineralized by the weather. Peat decomposition is enhanced by NPK fertilization [17]. Nitrogen deposition raises to the degree that conceals crop capacity to absorb N and the net of N mineralization in the surface will be withdrawn by higher \( \text{NH}_4^+ \)-N availability. In comparison, net of nitrification will be accelerated by higher \( \text{NH}_4^+ \)-N availability [19].

### 3.2. Shallot growth and nutrient uptake

The type of liming materials had a different effect on plant growth, plant height and leave's number (Table 2). The liming materials affected shallot biomass and nutrient uptake, while the application of NPK fertilizer did not significantly affect it (Table 3).

#### Table 2. The effect of liming materials and NPK fertilizer on shallot growth

| Treatments                             | Plant Height (cm) | Number of leaves |
|----------------------------------------|-------------------|-----------------|
|                                        | 4-wap | 6-wap | 4-wap | 6-wap |
| Liming materials:                      |   |      |      |     |
| 3 t/ha Dolomite                        | 24.0 | 24.5 | 15.1 | 17.3 |
| 3 t/ha Agriculture limestone           | 26.6 | 28.0 | 18.1 | 20.5 |
| 1.5 t/ha Hydrated lime                 | 27.6 | 28.4 | 17.6 | 20.7 |
| NPK levels (N-P2O5-K2O)                |   |      |      |     |
| P1 (0-100-200)                         | 25.4 | 26.3 | 15.78 | 18.9 |
| P2 (150-100-200)                       | 25.8 | 25.3 | 15.18 | 17.5 |
| P3 (300-100-200)                       | 24.7 | 27.3 | 17.57 | 19.3 |
| P4 (150-0-200)                         | 26.7 | 25.3 | 15.12 | 18.5 |
| P5 (150-200-200)                       | 25.3 | 26.8 | 17.60 | 19.2 |
| P6 (150-300-200)                       | 25.3 | 28.2 | 17.55 | 20.8 |
| P7 (150-100-0)                         | 26.5 | 27.8 | 18.80 | 21.2 |
| P8 (150-100-100)                       | 27.2 | 29.2 | 18.20 | 21.7 |
| P9 (150-100-300)                       | 27.4 | 27.4 | 17.70 | 20.0 |
| P10 (150-100-400)                      | 26.5 | 27.4 | 17.70 | 20.0 |
| CV (%)                                 | 8.79 | 11.47 | 20.00 | 18.66 |

Wap=weeks after planting; ns=not significant; means presenting the same letter are not statistically different by DMR at \( \alpha=5\% \).

The effect of liming materials on shallot growth (plant height leaves number, biomass and NPK uptake) relies on the soil properties of the peat soil. The application of lime improves plant growth by improving soil condition. Lime improves the soil structure directly and improves the chemical properties of the soil by increasing the soil pH [20]. Moreover, an abundant organic-P in the peat soil was quickly turned over to supply inorganic to shallot roots and promote shallot growth [21].

Lime materials increase plant growth through increasing soil pH that improves the root growth [22]. Shallot has shallow and hairless roots that make it susceptible to very acidic soil situation when the plant available-P is limited while high concentration of exchangeable acidity is toxic for the crop. There is a relationship between Al toxicity and P-uptake.
Table 3. The effect of liming materials and NPK fertilizer on nutrients content.

| Treatment                      | N content (mg/plant) | P content (mg/plant) | K content (mg/plant) |
|--------------------------------|----------------------|----------------------|----------------------|
| **Liming materials:**          |                      |                      |                      |
| 3 t/ha Dolomite                | 36.0<sup>b</sup>     | 6.3<sup>b</sup>      | 50.2<sup>b</sup>     |
| 3 t/ha Agriculture limestone   | 55.2<sup>a</sup>     | 9.1<sup>a</sup>      | 78.9<sup>a</sup>     |
| 1.5 t/ha Hydrated lime         | 51.1<sup>a</sup>     | 8.7<sup>a</sup>      | 73.2<sup>a</sup>     |
| **NPK levels (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O):** | |                      |                      |
| P1 (0-100-200)                 | 47.4<sup>ns</sup>    | 8.7<sup>ns</sup>     | 69.2<sup>ns</sup>    |
| P2 (150-100-200)               | 47.2                 | 7.7                  | 70.1                 |
| P3 (300-100-200)               | 46.9                 | 7.6                  | 64.7                 |
| P4 (150-0-200)                 | 46.7                 | 7.6                  | 64.5                 |
| P5 (150-200-200)               | 47.6                 | 8.0                  | 66.2                 |
| P6 (150-300-200)               | 49.9                 | 8.6                  | 69.8                 |
| P7 (150-100-0)                 | 51.0                 | 8.4                  | 68.8                 |
| P8 (150-100-100)               | 47.0                 | 7.8                  | 65.9                 |
| P9 (150-100-300)               | 42.8                 | 7.1                  | 63.2                 |
| P10 (150-100-400)              | 50.0                 | 8.7                  | 71.9                 |
| **CV (%)**                     | 33.98                | 29.18                | 30.40                |

ns = not significant; means presenting the same letter are not statistically different by DMRT at α=5%.

3.3. Bulb yield
The type of liming materials and fertilizers significantly affected the bulb yield parameters (Table 4). The application of agricultural limestone and hydrated lime had a higher bulb yield compared to dolomite. The fresh bulb yield of agriculture limestone treatment was 28% higher than dolomite, and the fresh bulb yield of hydrated lime was 46% higher than dolomite. The best NPK fertilizer was 150 kg N + 100 kg P<sub>2</sub>O<sub>5</sub> + 100 kg K<sub>2</sub>O that significantly different with other NPK rates.

Table 4. The effect of lime material types and NPK fertilizer on shallot bulb yield

| Treatment                      | Number of the bulb (per plant) | Fresh bulb yield (mg/plant) | Fresh bulb yield (t/ha) |
|--------------------------------|--------------------------------|-----------------------------|-------------------------|
| **Lime materials:**            |                                |                             |                         |
| 3 t/ha Dolomite                | 4.9<sup>b</sup>               | 2352<sup>b</sup>           | 3.9<sup>b</sup>         |
| 3 t/ha Agriculture limestone   | 5.9<sup>a</sup>               | 3005<sup>a</sup>           | 5.0<sup>a</sup>         |
| 1.5 t/ha Hydrated lime         | 6.1<sup>a</sup>               | 3414<sup>a</sup>           | 5.7<sup>a</sup>         |
| **NPK levels (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O):** |                             |                             |                         |
| P1 (0-100-200)                 | 4.4<sup>c</sup>               | 2052<sup>c</sup>           | 3.4<sup>c</sup>         |
| P2 (150-100-200)               | 4.8<sup>c</sup>               | 2358<sup>c</sup>           | 3.9<sup>c</sup>         |
| P3 (300-100-200)               | 5.2<sup>abc</sup>             | 3056<sup>b</sup>           | 5.1<sup>b</sup>         |
| P4 (150-0-200)                 | 5.4<sup>abc</sup>             | 2529<sup>bc</sup>          | 4.2<sup>bc</sup>        |
| P5 (150-200-200)               | 5.2<sup>abc</sup>             | 2545<sup>bc</sup>          | 4.2<sup>bc</sup>        |
| P6 (150-300-200)               | 5.8<sup>ab</sup>              | 2836<sup>b</sup>           | 4.7<sup>b</sup>         |
| P7 (150-100-0)                 | 6.3<sup>a</sup>               | 2965<sup>b</sup>           | 4.9<sup>b</sup>         |
| P8 (150-100-100)               | 6.5<sup>a</sup>               | 4183<sup>a</sup>           | 7.0<sup>a</sup>         |
| P9 (150-100-300)               | 6.3<sup>a</sup>               | 3356<sup>b</sup>           | 5.6<sup>b</sup>         |
| P10 (150-100-400)              | 6.4<sup>a</sup>               | 3359<sup>b</sup>           | 5.6<sup>b</sup>         |
| **CV (%)**                     | 28.78                          | 35.12                       | 35.12                   |

ns = not significant; means presenting the same letter are not statistically different by DMRT at α=5%.

The application of hydrated lime 1.5 t/ha gave a higher yield due to the ability of hydrated lime to alter soil pH was higher than other liming materials. The soil pH in hydrated lime treatment was higher
than dolomite and agriculture limestone. A similar result was reported that shallot bulb yield increased by the alteration of soil pH [23].

Hydrated lime composes of pure calcium carbonate without magnesium and has > 100% calcium carbonate equivalence (CaCO₃). Agricultural limestone contains > 85% CaCO₃, meanwhile dolomite has 30% CaO and 18-22% MgO with > 100% CaCO₃. Shallot gave a better result in the high Ca/Mg ratio rather than a low Ca/Mg ratio. The decreasing of Ca/Mg ratio reduces bulb yield due to onion assimilates Mg more easily than Ca. High soil pH will hydrate lime treatment and increase Ca²⁺ contents. However, there was no analysis of Ca²⁺ content in this experiment.

The best treatment for NPK fertilizers was P8, 150 kg N ha⁻¹ + 100 kg P₂O₅ ha⁻¹ + 100 kg K₂O ha⁻¹. The application of NPK fertilizers increased the shallot yield. The application of 0 kg N ha⁻¹ + 100 kg P₂O₅ ha⁻¹ + 200 kg K₂O ha⁻¹ (P1) had the lowest bulb yield among the treatments. The application of N fertilizer has a synergy effect with phosphorus fertilization. The combine application of NPK fertilizers give a positive impact on the shallot bulb yield. The lowest bulb yield in P1 (0 N) indicates the importance of nitrogen as an essential nutrient. This finding agrees with other results in several studies. The application of 60 kg N ha⁻¹ increased the onion bulb yield by 18%, and the application of 120 kg N ha⁻¹ increased the onion bulb yield by 29% [4]. Abdissa [24] reported that the application of 69 kg N ha⁻¹ increased the bulb yield up to 18% than control, 0 N. Inadequate supply of nitrogen makes onions to keep growing and reduce the bulb size and marketable bulb yield. However, exaggerate N application increases the vegetative growth, delay the maturity, reduces the resistance of onion on diseases, and also enhances the weight loss of bulb during the storage period [25].

Moreover, an exaggerate K fertilizer rate also decreases the onion bulb yield. In this experiment, 200 kg K₂O ha⁻¹ (P2) had a lower bulb yield compared to 100 kg K₂O ha⁻¹ (P8). The similar result was reported by Suparman et al [11] that found the dry bulb yield increased by lime application but reduced in the very high of potassium level. Furthermore, a high dose of potassium fertilizer (>180 kg K₂O/ha) also increased bulb weight loss during the storage period [11].

The highest shallot bulb yield in this experiment was 7 t/ha. This result was similar with Firmansyah et al [26] who reported that the fresh bulb yield of shallot cultivar ‘Bima’ in peat soils was 7.2 t/ha. However, the difference of cultivar might give a different result as stated. For instance, Reflinur et al [27] found that the shallot bulb yield of ‘Sembrani’ cultivar was 14.2 t/ha and ‘Tiron’ cultivar was 11.6 t/ha when grown in peat soil. In comparison, ‘Bima’ cultivar had a better yield compared to ‘Kampar’ and ‘Medan’ cultivar in organic soil condition [28]. It was assumed that using different cultivar that more tolerant than ‘Bima’ might increase the bulb yield and possibly show a better response of shallot growth and yield on lime and fertilizer application.

4. Conclusion
The application of 1.5 t ha⁻¹ hydrated lime had the best result compared to other liming materials, dolomite and agriculture limestone. The best NPK fertilizer rate was 150 kg N ha⁻¹, 100 kg P₂O₅ ha⁻¹ and 100 kg K₂O ha⁻¹. However, the optimum yield, 7 t ha⁻¹, was lower compare to other cultivars in previous studies. Further study using a higher rate of lime and adapted variety is necessary to achieve the maximum yield.

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