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The soil available P, Plant P uptake, Growth, and yield of corn in Regosol Soil Treated with Ela Sago Compost and SP-36 Fertilizer

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ABSTRACT

The research examined the effect of ela sago compost on the soil chemical properties, growth, P-uptake, and yields of corn plants (Zea *mays* L) in Regosol soils. A randomized block design with a 2 x 4 factorial treatment was applied. The first factor was ela sago compost (B) with three dose levels: B0 = 0-Mg ha^{-1}, B1 = 10-Mg ha^{-1}, and B2 = 20-Mg ha^{-1}. The second factor was SP-36 (P) fertilizer with four dose levels: P0 = 0 kg P ha^{-1}, P1 = 60 kg P ha^{-1}, P2 = 120 kg P ha^{-1}, and P3 = 180 kg P ha^{-1}. This research shows that either ela sago compost or SP-36 fertilizer can increase the soil reaction (pH). Applying sago palm compost and SP-36 fertilizer increases soil available P from 17.33 to 60.67 ppm. Applying sago palm compost and SP-36 fertilizer increases plant P-uptake from 0.18 to 0.40 %, plant height from 135.60 to 189.67 cm, and stem diameter from 1.86 to 3.44 cm, and corn yield (dry weight of 1000 seeds) from 266.60 to 390.57 g.

Keywords: Ela sago, corn, compost, regosol, SP-36 fertilizer

INTRODUCTION

Regosol soil is a young soil characterized by a profile appearance with few horizons, developed from alluvium parent material and loose material. It has the following characteristics: (1) medium to deep solum (60-150cm), (2) soil texture from the top layer to the bottom layer is dominated by sand, (3) without structure, (4) loose consistency, (5) the color of the top soil layer is very dark gray-brown, the further down layer gets more yellow. Additionally, regosol is a moderate to low fertility soil because it has low organic matter content caused by very high leaching. Therefore, soil reaction values range from slightly acidic to alkaline and are poor in N, P, and K nutrients. Cation exchange capacity and base saturation are relatively low (Azmi et al., 2015). The main problems with the Regosol soil type are low organic matter (C-organic), total N, and available P contents (Manurung, 2013; Kumolantang et al., 2017; Kaya et al., 2022).

Regosol soil is also characterized by low water-holding capacity. Because the spaces between the grains are large, the water permeability is also significant, so it is less able to bind and contains less water and nutrients (drainage and aeration work well, usually in a loose state). Adding organic material can improve soil structure because organic material acts as an adhesive between single grains. Organic matter also increases regosol soil water-holding capacity and cation exchangeability.

Phosphorus is a macro essential nutrient primarily needed by plants. Not all phosphorus is available to plants; in this case, it really depends on the soil's nature and characteristics and the soil's management by humans. Besides, the increase in soil phosphorus does not occur due to biochemical bindings such as nitrogen; it comes from deposits or rocks and minerals containing phosphorus. Soil phosphorus levels are also determined by the availability of large or small reserves of minerals containing phosphorus.

One effort to increase soil solution P and reduce P deficiency is the application of P fertilizer. Based on research results (Soelaeman & Haryati, 2012; Kaya et al., 2022), applying P fertilizer can increase the availability of P in both newly developed and developing soils. Furthermore, research by Sopha et al. (2021) supports the idea that continuous P fertilization on agricultural land cultivated for an extended period can increase soil P-availability to moderate levels.

Adding organic fertilizer (organic material) to the soil can increase its physical, chemical, and biological fertility. Organic fertilizer (organic material) is also used as green manure, manure (animal waste), and compost. Composts have resulted from the decomposition/weathering of organic waste (plant residues, harvest residues, food waste, and animal waste) by microbes in suitable environmental conditions with sufficient water, air, and heat. Sago palm is one of the harvest residues that can be used with cow dung to make compost. Sago palm as sago processing waste is the fiber from the inside of the sago tree, which is thrown away after the starch has been extracted. According to research by Kaya et al. (2010), Ela sago has pH 4.5 and contains K-total 0.03 %, Ca 0.16 %, Mg 0.14 %, Na-total 0.34 %, N-total 0.94 %, P-total 0.63 %, C-organic 48.88 %, C/N 52.0, Water Content 49.60%, Ash content 15.73%. So far, Ela sago has only been used as animal feed and a medium for growing mushrooms. However, Ela sago is always produced during sago starch processing, so if left untreated, it can pollute the environment. Therefore, Ela Sago will be used as an organic fertilizer (compost).

Sago palm compost can improve soil properties. Kaya et al. (2008) show that the application of sago palm compost (80 Mg ha^{-1}) with urea fertilizer (260 kg ha^{-1}) improves the chemical properties of Regosol soil by increasing soil available N from 0.17 % to 0.27 % and Plant N uptake from 3.17 % to 3.59 %. Applying 40-Mg compost ha^{-1} and 260 kg Urea ha^{-1} also improves the physical properties of Ultisol soil by reducing bulk density, increasing particle density and soil porosity, the distribution of soil pore sizes (slow-draining and fast-draining pores, increasing available pore water), improving the stability of soil aggregates. Moreover, applying 80-Mg ha^{-1} sago palm compost increases the growth of mustard greens (*Brassica juncea*) by increasing plant height from 21.38 to 30.70 cm and leaf number from 8.44 to 10.67 pieces.

Kaya (2009) found that applying ela sago bokashi 80-Mg ha^{-1} and phosphate fertilizer 120 kg P ha^{-1} were able to increase soil pH by 6.07 while applying ela sago bokashi 80-Mg ha^{-1} and phosphate fertilizer 240 kg ha^{-1} were able to increase soil P-available by 16.23 ppm. Meanwhile, applying ela sago bokashi 80-Mg ha^{-1} or phosphate fertilizer 120 kg P ha^{-1} increased P-uptake by 0.168 % and 0.169 %, respectively. In contrast, combining ela sago bokashi 80 Mg ha^{-1} with phosphate fertilizer 240 kg ha^{-1} increased the dry weight yield of corn kernels by 6.77 Mg ha^{-1}.

The research objectives are to examine the effects of sago waste (ela sago) as an organic fertilizer and SP-36 fertilizer on soil P availability, plant P uptake, and the growth and yield of corn (*Zea mays* L.) on Regosol soil.

MATERIALS AND METHODS

The research was conducted in the Rumahtiga Village, Teluk Ambon District, Ambon City field from April to October 2021. Meanwhile, soil and plant samples were analyzed at the Soil Chemistry Laboratory of the Bogor Soil Research Institute.

The experiment was conducted in the field with a 3 × 4 factorial pattern arranged in a Randomized Block Design with three replications.

The first factor was the application of Ela Sago compost (B) with four dose levels: B0 = 0-Mg ha^{-1}, B1 = 10-Mg ha^{-1}, and B2 = 20-Mg ha^{-1}. The second factor was the application of P fertilizer (SP-36,) with 4 dose levels, namely: P0 = 0 kg ha^{-1}, P1 = 60 kg ha^{-1} , P2 = 120 kg ha^{-1}, and P3 = 180 kg ha^{-1}.

The experiment was carried out on the Regosol soil type. Before processing, the land was cleaned of grass, then processed with a hoe to a depth of 0.25 m and leveled. After that, 2 m × 1 m plots were made trenches 0.30 m deep between the plots, and channels were made 0.40 m wide and 0.30 m deep for separation between replications. The experimental plots were 36, and each treatment plot was named according to the treatment combination. Next, each treatment plot was given sago palm compost mixed with soil and incubated for 2 weeks. Then, two corn seeds were planted per planting hole at a spacing of 0.80 m x 0.20 m while SP-36 fertilizer was applied individually according to the treatment plot. A week after growing, one plant per planting hole was selected. The data collected consisted of response variable data that was determined and analyzed statistically, as well as other supporting data that was not analyzed statistically. The response variables analyzed statistically were as follows: P-available, soil pH, plant P uptake, corn plant growth (plant height and stem diameter), and plant yield (dry weight of 1000 seeds) of corn.

Data were analyzed using univariate analysis of variance, while differences were tested using the BNT test (Steel & Torrie, 1995).

RESULTS AND DISCUSSION

Experimental Soil Characteristics

The chemical analysis results of Regosol soil before planting are shown in Table 1.

Table 1. Complete analysis data for Regosol soil before planting.

Analyzed Component	Regosol	Criteria *
pH H_2O	6.4	slightly acid
C (%)	2.11	medium
N (%)	0.20	low
C/N	11.0	medium
P_2O_5 (ppm)	13.0	low
Ca (me $100g^{-1}$)	11.17	high
Mg (me $100g^{-1}$)	0.34	very low
Na (me $100g^{-1}$)	0.22	low
K (me $100g^{-1}$)	0.10	low
Base saturation (%)	>100	very high
Al-dd (me $100g^{-1}$)	0.0	-
H-dd (me $100g^{-1}$)	0.0	-
KTK (me $100g^{-1}$)	4.30	very low
Texture:		
Sand (%)	85.0	
Clay	7.0	sand
Silt	8.0	

Note: *) PPT, 1993 Criteria (Hardjowigeno, 2007). Source: Soil Chemistry Laboratory of the Soil Research Institute, Bogor

The base saturation is very high, while the soil's CEC is very low. The exchangeable bases (Ca, Mg, Na, and K) contents in the soil ranged from very low to high. The texture with the sand, clay, and silt particles ratios are 85.0%, 8.0%, and 7.0%, respectively, included in the sand class.

Based on these characteristics, the Regosol soil type for the experiment has a generally low fertility level. Thus, efforts are needed to improve fertility before it is used as agricultural land for corn cultivation.

Ela Sago Compost

The analysis results of ela sago compost are pH 7.6, C-organic 10.27 %, N-total 1.19 %, C/N ratio 8,63, CEC value 39.27 me $100g^{-1}$, P-total 1.04 %, K-total 0.56 %, Ca-total 0.52 %; and Mg-total 0.21 %.

Changes in the pH of the compost start from a slightly acidic due to the formation of simple organic acids. The pH increases with further incubation due to the decomposition of proteins and the release of ammonia, which lasts until the formation of ammonium. The changes in soil pH during organic material degradation result from soil microorganism activity (Firdaus, 2011; Ismayana et al., 2012). The C-organic content decreases due to decomposition. A C/N ratio <20 means that the organic waste mineralization or decomposition process is going well so that nutrients become available and can be absorbed by plant roots (Hanafiah, 2005). Suwatanti and Widiyaningrum (2017) show that the compost contents with vegetable waste MOL are pH 7.0; C-Organic 19.37 %, N-total 1.37 %, C/N 14.13, P_2O_5 0.56 %, and K_2O 0.73 %.

Soil reaction (pH)

The results showed that applying either Ela sago compost or phosphate fertilizer affected soil pH. In contrast, the interaction between the two had no significant effect on soil pH.

Table 2 shows that applying ela sago compost 20-Mg ha^{-1} has higher soil pH than the control, but it is not significantly different with 10-Mg ha^{-1} at 120 kg ha^{-1} phosphate fertilizer. Likewise, applying more than 120 kg P ha^{-1} increases soil pH than without P at 10 and 20 t compost ha^{-1}. Applying 20 Mg of compost ha^{-1} with 120 kg P ha^{-1} is the best for increasing soil pH from 5,8 to 6,7. By adding compost to the soil, the decomposition of organic material produces organic acids which react with the hydroxyl groups of Al and Fe, as well as H^+ ions to form a ligand circle, which liberates OH^- ions, resulting in organo-complex compounds with Al, Fe and H ions in the soil which were initially high can be reduced or decreased causing the soil pH to increase (Hue, 1992; Kaya, 2012; Kaya et al., 2022). Besides, applying phosphate fertilizer to the soil will increase soil pH due to the release of OH^- ions into the solution due to the adsorption of phosphate anions ($H_2PO_4^-$) by Al and Fe oxides, as Ca^{2+} ions in

Table 2. Soil reaction (pH) by applying Ela Sago Compost and Phosphate Fertilizer in Regosols.

Ela Sago Compost ($Mg\ ha^{-1}$) (B)	Phosphate Fertilizer ($kg\ P\ ha^{-1}$) (P)			
	P_0 (0)	P_1 (60)	P_2 (120)	P_3 (180)
	.... Soil pH			
B_0 (0)	5.8 a	6.00 a	6.03 a	6.27 a
	A	A	A	A
B_1 (10)	6.0 a	6.07 a	6.37 ab	6.57 a
	A	A	AB	B
B_2 (20)	6.13 a	6.47 a	6.70 b	6.57 a
	A	AB	B	AB

Notes: Numbers followed by different letters towards each column (lower case) and row (upper case) are significant according to the SDR test 5% = 0.49.

phosphate fertilizer will replace H^+ and Al^{3+} ions in adsorption complex so that the concentration of H^+ ions in the soil solution decreases and OH^- ions increase so that the soil pH increases (Afif et al., 1993; Kaya, 2009).

Phosphate Availability

The results showed that applying ela sago compost and phosphate fertilizer and their interactions significantly increased soil availability P.

Table 3 shows that applying ela sago compost up to 20 $Mg\ ha^{-1}$ increased soil available P for all phosphate fertilizers.

On the other hand, applying phosphate fertilizer increased soil available P with the increasing Ela Sago Compost. The best combination to increase the soil available P is ela sago compost 20-$Mg\ ha^{-1}$ with 180 $kg\ P\ ha^{-1}$, 60.67 ppm. Regarding the soil available P, Kaya (2003) explained that organic materials' decomposition will produce organic acids, which can bind Al, Fe, and Ca ions from the soil solution. Organic acids will react with oxides and hydroxides to form organic complex compounds, decreasing P adsorption capacity and increasing P availability. Therefore, with sufficient organic acids, more phosphate will dissolve in the soil and be available to plants.

Aside from adding organic material, applying phosphate fertilizer in high doses can also provide soil available P. Providing P fertilizer has a significant effect on the soil available P; it also reduces retention because the adsorption site is saturated with phosphate, so the P availability increases (Kaya, 2018; Putriani, 2022). Besides, there is the element Ca in this fertilizer. Ca^{2+} ions will replace ions H^+, Al^{3+}, and Fe^{3+} in the adsorption complex, resulting in H^+ ions in solution decrease and the concentration of OH^- ions increases (Kaya, 2003).

P uptake

The results show that the application of ela sago compost and P fertilizer or their interaction significantly affected the increase in plant P-uptake. Table 4 shows the application of 20-$Mg\ ha^{-1}$ ela sago, and 180 $kg\ P\ ha^{-1}$ has the highest plant P-uptake.

Table 3. Soil available P with applying Ela Sago Compost with Phosphate Fertilizer in Regosols.

Sago Ela Compost ($Mg\ ha^{-1}$) (B)	Phosphate Fertilizer ($kg\ P\ ha^{-1}$) (P)			
	P_0 (0)	P_1 (60)	P_2 (120)	P_3 (180)
	.... Soil available P (ppm)			
B_0 (0)	17.33 a	23.00 a	30.33 a	35.67 a
	A	B	C	C
B_1 (10)	23.67 b	29.00 b	36.33 b	42.67 b
	A	A	B	C
B_2 (20)	30.00 c	42.00 c	54.67 c	60.67 c
	A	B	C	D

Notes: Numbers followed by different letters towards each column (lower case) and row (upper case) are significant according to the SDR test 5% = 5.46.

Table 4. P Uptake of Corn Plants When Given Ela Sago Compost With Phosphate Fertilizer in Regosol Soil.

Sago Ela Compost ($Mg\ ha^{-1}$) (B)	Phosphate Fertilizer ($kg\ P\ ha^{-1}$) (P)			
	P_0 (0)	P_1 (60)	P_2 (120)	P_3 (180)
	.... P uptake (%)			
B_0 (0)	0.18 a	0.23 a	0.25 a	0.28 a
	A	B	BC	C
B_1 (10)	0.25 b	0.28 b	0.30 b	0.34 b
	A	AB	BC	C
B_2 (20)	0.30 c	0.39 c	0.46 c	0.40 c
	A	B	C	B

Notes: Numbers followed by different letters towards each column (lower case) and row (upper case) are significant according to the SDR test 5% = 0.04.

At each dose P, the soil available P increases with the increasing ela sago compost dose. P fertilizers (60 to 180 kg P ha^{-1}) increase soil available P compared to those without P fertilizer. Applying phosphate fertilizer together with 20 Mg ha^{-1} of ela sago compost shows that increasing the dose of phosphate fertilizer to 120 kg P ha^{-1} increases the plant P-uptake from 0.30 to 0.46 %, but if it is added more doses up to 180 kg P ha^{-1} resulted in a decrease of plant P uptake to 0.40 %. Increasing the dose of ela sago compost to 20 Mg ha^{-1} with the highest phosphate fertilizer dose of 180 kg ha^{-1} tends to reduce P uptake. The P element in the compost that plants can absorb is reduced due to competition between plants and microorganisms. As a result, the P element absorbed by plants becomes low. The highest plant P-uptake value was in treating 20 Mg ha^{-1} of sago palm compost and 120 kg P ha^{-1} of phosphate fertilizer, which was 0.46 %. Organic matter can form soil aggregates by binding complex organic compounds with primary particles so that P can be fixed in the solid phase, causing increased soil P availability and, as a result, increasing plant P uptake.

Furthermore, organic materials as a source of N, P, and S elements are bound in organic form or the bodies of microorganisms and can form complexes with microelements so that these elements are protected from leaching and will be available again after the microbodies die (Hardjowigeno, 2007). Adding organic matter improves the soil structure so that root development becomes better at absorbing P nutrients. Phosphorus (P) is a part of the cell nucleus that is very important in cell division and the development of meristem tissue, so it can stimulate root growth and young plants, causing absorption of the increasing element nutrients (Kaya, 2003; Sufardi, 1999; Nuryani et al., 2019). The P element given to the soil as fertilizer can saturate the P because the solid phase adsorbs it. As a result of this saturation, most of the P will be available in the soil, along with increasing plant P uptake.

Corn Plant Growth

Plant height

The results show that the application of ela sago compost and phosphate fertilizer and their interactions significantly affected plant height.

Table 5 shows that applying 20-Mg ha^{-1} ela sago compost with 120 kg P ha^{-1} had higher corn plant height than 0- and 10-Mg ha^{-1} ela sago compost. On the other hand, plant height with the application of 180 kg P ha^{-1} was higher than without phosphate fertilizer without sago ela compost. In contrast, plant height with the application of ela sago compost, either 10 or 20 Mg ha^{-1}, was not different without phosphate fertilizer treatment. The highest plant height was in the treatment of ela sago compost 20 Mg ha^{-1} with 180 P kg ha^{-1}, 189.67 cm.

The increase in plant height due to the application of sago palm compost is related to the increase in the availability of phosphorus in the soil, which can increase phosphorus uptake by plants. This uptake is closely correlated with meristem tissue development, so it determines plant growth (Kaya, 2012, 2018; Kaya et al., 2022).

Phosphate fertilizer can provide a source of nutrients such as P and microelements (Fe, Zn, Mo). The P element in plants is a constituent of cell nuclei, cell division, and the development of meristem tissue. P element is also needed for the formation of carbohydrates and accurate mechanisms of chloroplast activity and metabolic activities, as well

Table 5. Plant Height of Corn with the application of Sago Compost and Phosphate Fertilizer in the Regosol Soil.

Sago Ela Compost (Mg ha^{-1}) (B)	Phosphate Fertilizer (kg P ha^{-1}) (P)			
	P_0 (0)	P_1 (60)	P_2 (120)	P_3 (180)
	.... Plant height (cm)			
B_0 (0)	135.60 a	154.47 a	166.23 a	171.87 a
	A	B	B	B
B_1 (10)	163.40 b	174.53 b	159.07 a	181.13 a
	AB	AB	A	B
B_2 (20)	187.33 c	165.13 ab	185.33 b	189.67 a
	B	A	B	B

Notes: Numbers followed by different letters towards each column (lower case) and row (upper case) are significant according to the SDR test 5% = 18.44.

as influencing the quality of plant results. In other words, element P supports plant growth and development (Fahmi et al., 2010; Kasno, 2019; Munawar, 2018). Besides, microelements such as Fe, Zn, and Mo can function as electron carriers in enzyme systems that cause oxidation-reduction reactions in plants, which are helpful for plant development and propagation.

Stem Diameter

The results showed that the application of ela sago compost and phosphate fertilizer and their interaction significantly increased the diameter of corn stalks.

Table 6 shows that the application of ela sago compost, 20 Mg ha^{-1}, had a higher stem diameter than 10 Mg ha^{-1} or without ela sago compost when 120 and 180 kg P ha^{-1} were applied. Stem diameter with the application of ela sago compost 20 Mg ha^{-1} was higher than other ela sagu doses with 0 and 60 kg P ha^{-1}. The highest corn stalk diameter was found in 20 Mg ha^{-1} of ela sago compost and 180 kg P ha^{-1}, namely 3.44 cm.

Providing sago palm compost and phosphate fertilizer can affect stem diameter because, in addition to the macronutrients N, P, and K, the micronutrients Fe and Zn are also available and absorbed by plants for vegetative plant growth.

Corn Yields

The results show that the application of ela sago compost and phosphate fertilizer and their interaction significantly increased the dry weight of 1000 corn kernels.

Table 7 shows that applying 20-Mg ha^{-1} ela sago compost and 120 kg P ha^{-1} had the highest dry weight of 1000 corn seeds. At all fertilizer dose applications, the dry weight of 1000 corn seeds increased with the increasing dosages of ela sago

Table 6. Diameter of Corn Stalks with the application of Sago Ela Compost and Phosphate Fertilizer in Regosol Soils.

Sago Ela Compost (Mg ha^{-1}) (B)	Phosphate Fertilizer (kg P ha^{-1}) (P)			
	P_0 (0)	P_1 (60)	P_2 (120)	P_3 (180)
	.... Stem Diameter (cm)			
B_0 (0)	1.86 a	1.95 a	2.03 a	2.19 a
	A	A	A	A
B_1 (10)	1.89 a	2.21 ab	2.48 b	2.57 b
	A	AB	BC	C
B_2 (20)	2.35 b	2.49 b	3.02 c	3.44 c
	A	A	B	C

Notes: Numbers followed by different letters towards each column (lower case) and row (upper case) are significant according to the SDR test 5% = 0.35

Table 7. Dry Weight of 1000 Corn Seeds when given Ela Sago Compost with Phosphate Fertilizer On Regosol Soil.

Sago Ela Compost ($Mg\ ha^{-1}$) (B)	Phosphate Fertilizer ($kg\ P\ ha^{-1}$) (P)			
	P_0 (0)	P_1 (60)	P_2 (120)	P_3 (180)
	.... Dry Weight of 1000 Corn Seeds (g)			....
B_0 (0)	266.60 a	271.67 a	323.37 a	341.33 a
	A	A	B	B
B_1 (10)	335.27 b	344.30 b	355.30 b	364.87 b
	A	AB	AB	B
B_2 (20)	359.80 c	374.00 c	390.37 c	364.63 b
	A	AB	B	A

Notes: Numbers followed by different letters towards each column (lower case) and row (upper case) are significant according to the SDR test 5% = 20.65.

composts. At all ela sago compost dose applications, dry weight 1000 corn seeds at 180 kg P ha^{-1} is higher than other phosphate fertilizer treatments.

Putriani et al. (2022) stated a positive correlation between available P and P absorption: the higher the P available, the higher the P absorbed. Phosphorus is absorbed by plants in the form of $H_2PO_4^-$ and HPO_4^{2-} ions; therefore, the more P is available in the soil, plant roots will absorb the more P. P absorption on the root surface is faster than the movement of phosphate to the root surface because the phosphate concentration is very low around the root surface (Aprillianda, 2012; Sagala et al., 2013). Apart from that, there is also a close relationship between P uptake and sweet corn yield, where the higher the P absorbed by plant roots, the greater the production of corn plants. Phosphorus is one of the nutrients that make up energy transfer components, nucleic acids, and main enzyme constituents; it stimulates initial root growth and plant growth, accelerates seed growth, and many other metabolic functions.

CONCLUSIONS

Applying either ela sago compost or SP-36 fertilizer increased soil pH. Applying ela sago compost and SP-36 fertilizer increased soil available P from 17.33 to 60.67 ppm, plant P-uptake from 0.18 to 0.40%, corn plant height from 135.60 to 189.67 cm, stem diameter from 1.86 to 3.44 cm, and dry weight of 1000 corn kernels from 266.60 g to 390.57 g. The best combination to increase P uptake and dry weight of 1000 corn kernels was the application of ela sago compost 20 Mg ha^{-1} and phosphate fertilizer 120 kg ha^{-1}. The best combination to increase soil available P, plant height, and stem diameter was applying ela sago compost 20 Mg ha^{-1} and phosphate fertilizer 180 kg ha^{-1}.

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