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Rice Yields and Soil Nutrients Response to Liming Method and Dosages in Field Cultivation

(Hasil Padi dan Gerak Balas Nutrien Tanah terhadap Kaedah Pengapuran dan Dos dalam Penanaman Ladang)

ZHOU JIANG-MING*

ABSTRACT

It is important to develop a new convenient and environmentally-friendly technology of liming for sustainable rice production on acidic soil area. Thus, an experiment was conducted to evaluate the effect of application methods and rate of lime on soil properties and rice yield. The results showed that a similar ameliorating effect on agricultural acidic soil were found between massive quicklime and powered hydrated lime. Interestingly, optimized application rate of lime significantly increases rice yield, while over-liming leads to an adverse effect to the rice production. The changes of soil nutrients affected by liming rates were related to organic matter content and soil texture, with elevated mineralization of organic matter were found in organic and sandy soil. Conclusively, massive quicklime method has been found to be optimal for rice cultivation on acidic soil conditions with rates of 1500-2250 kg/ha for clay soil and 2250-3000 kg/ha for sandy soil, respectively.

Keywords: Acidic soil; liming technique; rice growth

ABSTRAK

Pembangunan teknologi pengapuran yang mudah dan mesra alam amat penting untuk pengeluaran padi yang mampan di kawasan tanah berasid. Oleh itu, satu uji kaji telah dijalankan untuk menilai kesan kaedah aplikasi dan kadar kapur terhadap sifat tanah dan hasil padi. Keputusan menunjukkan bahawa kesan pembaikan yang sama pada tanah pertanian berasid didapati antara kapur tohor masif dan kapur tawar. Menariknya, kadar penggunaan kapur yang dioptimumkan telah meningkatkan hasil padi dengan ketara, manakala penggunaan kapur yang berlebihan membawa kepada kesan buruk terhadap pengeluaran padi. Perubahan nutrien tanah yang dipengaruhi oleh kadar pengapuran adalah berkaitan dengan kandungan bahan organik, tekstur tanah serta mineralisasi bahan organik yang tinggi ditemui dalam tanah organik dan berpasir. Secara kesimpulannya, kaedah kapur tohor masif memberikan hasil optimum bagi penanaman padi untuk tanah berasid dengan kadar masing-masing 1500-2250 kg/ha untuk tanah liat dan 2250-3000 kg/ha untuk tanah berpasir.

Kata kunci: Tanah berasid; teknik pengapuran; tumbesaran padi

INTRODUCTION

Soil acidification is well known as being one of the most yield-limiting factors with serious constraints to food production. Particularly, more than 50% of the world's arable land has been acidified by agricultural intensification, mainly via monoculture farming and excessive use of synthetic fertilizers (Li et al. 2018). The crops grown on these acidic soils were inhibited in growth by one or more factors such as toxicity of Al, Mn, or Fe; deficiencies of nutrients; enhanced incidence of root diseases or reduced breakdown rates of organic matter (OM) (Arshad et al. 2012; Kunito et al. 2016). Liming, a common and most effective managerial practice to ameliorate soil acidity and consequentially to improve crop production, have been used in agriculture for centuries. It has been characterized by raising soil pH and alleviating Al toxicity (Álvarez et al. 2009; Wijanarko & Taufiq 2016), elevating the N or P fertilizers recovery (Bailey 1995; Tucher et al. 2018), controlling crop diseases and pests (Gatch & Toit 2017), and consequently enhancing the yield of various crops (Karaivazoglou et al. 2007; Pagani & Mallarino 2015; Shamshuddin et al. 2016; Tang et al. 2003). Lime is usually applied as calcium carbonate (lime), calcium/magnesium carbonate (dolomitic lime), calcium oxide (burned lime), or calcium hydroxide (hydrated lime) (Gatch & Toit 2017; Paradelo et al. 2015), while the optimum material to effectively neutralize soil pH is calcium hydroxide (Li et al. 2018). However, application of calcium hydroxide is both time-consuming and labor-wasting under field conditions, and the occurrence of the powder dust during liming will pollute air environment as well as easily cause harm to operators' skin, especially eye cornea. Therefore, from the practical point of view, it is important to select the best environmental-friendly liming method with optimum dosage to increase rice production on acidic soil.

The principal aim of this work was to estimate the effect of two liming methods on rice growth and to quantify the optimum dosages in paddy field via two field experiments. The objectives of this study include: investigating the soil pH and rice yields under different lime application method; assessing the relationship between rice yields and lime dosages to determine an optimum liming dosage favoring rice growth on acidic soils; estimating the impact of different dosages of lime on OM, total nitrogen (TN), and available phosphorus (avai-P) in soils under field conditions.

MATERIALS AND METHODS

FIELD SITES

The study areas are situated in Quzhou, Zhejiang Province, a major crop production region in southern China. The climate is of subtropical monsoon type, with an annual average rainfall of approximately 1760 mm, of which 60% falls during monsoon season (April-June). Two series of field experiments were performed: a liming method experiment at the Gaojia town (GT), Qujiang city; and the liming dosage experiments represented by two sites in Jiangshan city, one at Hecun town (HT) with a soil texture of clay loam and the other at Qinghu town (QT) with a sandy loam. The detailed characteristics of paddy soils (0-15 cm topsoil) analyzed before the experiments are provided in Table 1.

TABLE 1. Soil characteristics before the establishment of the experiments

Soil	Unit	GT	HT	QT
Sand (>2 mm)	%	23.1	17.6	30.2
Silt (0.05-2 mm)	%	31.3	25.2	30.1
Silt (0.002-0.05 mm)	%	28.7	34.9	21.8
Clay (<0.002 mm)	%	16.9	22.3	17.9
pH		5.98	5.02	5.12
OM	g/kg	33.3	16.1	37.2
TN	g/kg	1.71	1.15	2.03
TP	g/kg	0.546	0.705	0.552
TK	g/kg	21.15	11.86	40.28
Avai-N	mg/kg	116.8	94.6	149.9
Avai-P	mg/kg	10.1	97	11.8
Avai-K	mg/kg	102	75	231

OM-Organic matter, TN-Total nitrogen, TP- Total phosphorus, TK- Total potassium, Avai-N-Available nitrogen, Avai-P-Available phosphorus, Avai-K-Available potassium

EXPERIMENTAL DESIGN

A single-crop rice of Zhongsu 143 was used as experiment material at GT. The early rice variety of Jinzao 47 for HT and Zhongzao 39 for QT, respectively, while late rice variety of Tongyou 1540 was cultivated at both sites. Sources of chemical fertilizers (N, P, K) used for this study were compound fertilizer (N 15%, P_2O_5 15%, K_2O 15%), urea (N 46%), triple superphosphate (P_2O_5 12%) and potassium chloride (K_2O 60%), respectively.

The experiment at GT began in April 2019 as a randomized complete block design replicated three times. A recommended lime rate of 2250 kg/ha was applied to two plots (3 m × 22 m) under flooded (5-7 cm) conditions, using massive quicklime (TM) or powdered hydrated lime (TP) as shown in Figure 1. The control plots received no lime. The liming material tested in this study was burned lime of different size and irregular mass shape purchased from a local quicklime mill (CaO, about 93%). It would be broken down into smaller pieces by hammer as presenting few large pieces in TM with weight more than 0.25 kg. Additionally, the powdered hydrated lime was made from reaction between quicklime and water by spraying water to massive lime. Lime was mixed manually with paddy soil to a depth of about 15 cm using iron rake one day after application on April 2. Rice was transplanted on April 3 and harvested on July 19 of the same year.

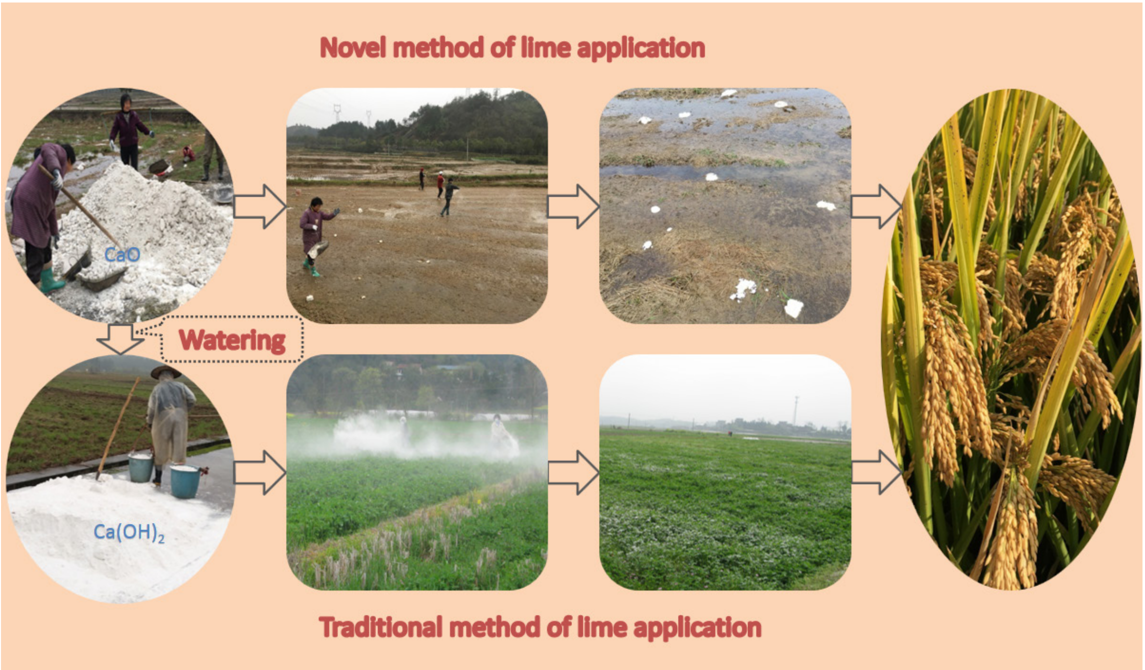

FIGURE 1. The new liming technique and traditional liming technique. TM, Massive quicklime (above); TP, Powdered hydrated lime (below)

The experiment at HT and QT began in April 2019 with six treatments in triplicates. Application rates of lime were 0, 750, 1500, 2250, 3000, and 3750 kg/ha in both experiments and were referred as T0, T1, T2, T3, T4, and T5, respectively. The experimental plot was randomly designed with an area of 35 m^2 (7 m × 5 m). Massive lime (quicklime) was applied and mixed into the soil one day before rice transplanting. Early rice was transplanted on 14-20 April and harvested on 16-22 July, subsequent late rice was transplanted on 20-23 June and harvested on 11-13 November, respectively.

Standard fertilizers (N, 135-210 kg/ha; P, 75-120 kg/ha; and K, 90-135 kg/ha) with twice applications were applied according to the dose of general regional recommendations at before and 4-7 days after rice transplant. Irrigation water, weeds, insects and diseases were controlled uniformly as required to avoid yield losses.

SOIL SAMPLING AND CHEMICAL ANALYSIS

During the experimental period at GT, the soil samples were taken (0-15 cm) at the end of 1, 3, 7, 30, and 105 (rice harvest) days of lime application. Eight samples were collected every time from eight regions of fixed position uniformly in each plot, and each sample was composed from five subsamples. While, for the experiments performed at HT and QT, soils were sampled at the end of 1, 7, 30, 90 (early rice harvest) and 205 (late rice harvest) days of lime application. The grain yield of each plot was weighted after rice harvest in all experiments.

Soil samples were air-dried, ground, passed through a 2-mm sieve following the measurement of texture in a subsample with a laser particle size analyzer (Mastersizer 3000). Soil pH was determined in a 1:2.5 (soil:water) suspension. OM was measured using potassium dichromate titration oxidation method (Mavi et al. 2018). Total nitrogen (TN) was analyzed by employing the Kjeldahl procedure, and available-N obtained by 2% H_3BO_3 titration after reducing the nitrate into ammonical nitrogen using a reductive of $FeSO_4$. Total phosphorus and total potassium content of soil samples were determined by the molybdenum blue-ascorbic acid method and flame photometer method after alkaline fusion ($Na(OH)_2$) at a temperature of 750 °C in nickel crucible, while extraction of soils with 0.025 M hydrochloric acid + 0.03 M ammonium fluoride for available-P and with 1 M CH_3COONH_4 (pH = 7.0) for available-K were analyzed using same way of TK and TP, respectively.

STATISTICAL ANALYSIS

A one-way ANOVA was carried out to compare the means of the all the investigated factors in different treatments during different periods. When significant F-values were detected, the difference between individual means were tested using the least significant difference (LSD) test. All analyses used the statistical software DPS v 9.5.

RESULTS

THE DYNAMICS OF SOIL PH AFFECTED BY APPLICATION METHOD AND RATES OF LIME

Regardless of liming method and lime rate in three tests, soil pH increased with lime application against the control (Figures 2 & 3). A similar tendency in all treatments were obtained which showed a quickly rose within a week after lime application and thereafter decreased gradually at the late stage. Among two application method of lime materials (Figure 2), the increase of soil pH had a similar effect with an exception at 7 days after lime application, where soil pH in TM treatment (7.52±1.1647) was significantly higher than in TP treatment (6.65±0.7883). Compared to the control, a significant elevation in soil

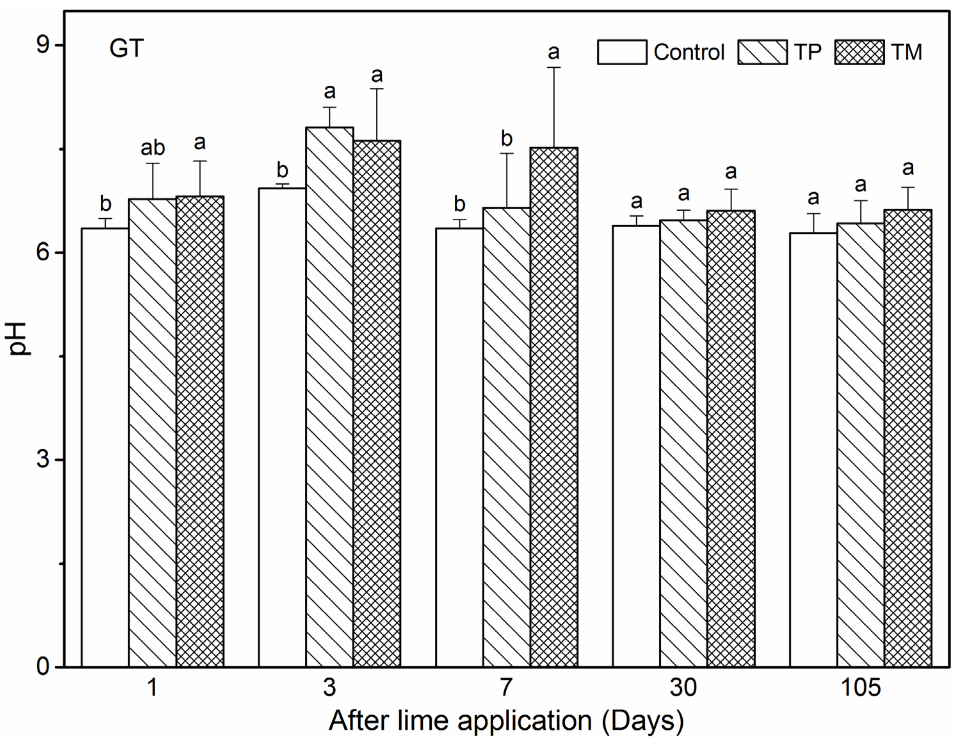

FIGURE 2. Soil pH of paddy field limed with different applying method during the rice growth period at Gaojia town site (GT) (error bars represent the % standard deviation, n=3; different letter above bars indicate a significant difference at *P*< 0.05 from each other at identical sampling day as determined by LSD method). TM, Massive quicklime; TP, Powdered hydrated lime

pH by 1.17 pH unit at 7 days after lime application for TM, and by 0.77 pH unit at 3 days lime application for TP was observed, respectively. Thereafter, no significant difference in soil-pH was noted between treatments until the end of experiment.

The subsequent experiments showed an increase in soil pH with an increase in liming rate. The maximum pH in liming treatments attained earlier at QT (1 day after lime application) than at HT (7 days) (Figure 3). The application rates of burned lime used from 750 to 3750 Mg/ha (T1 to T5) increased the soil pH at an average of 0.18 to 1.16 units for HT and 0.12 to 1.38 for QT across the whole experiment compared to control (T0), respectively. However, at the end of experiments, only soil pH amended with lime rates ranged from T2 to T5 at HT and T3 to T5 at QT were significantly higher than control (T0), and these treatments rose soil-pH above 0.5 units compared with that of before experiment simultaneously. These evidences indicate the minimum burned lime rate (>1500 Mg/ha) to effectively amend the acidic soils.

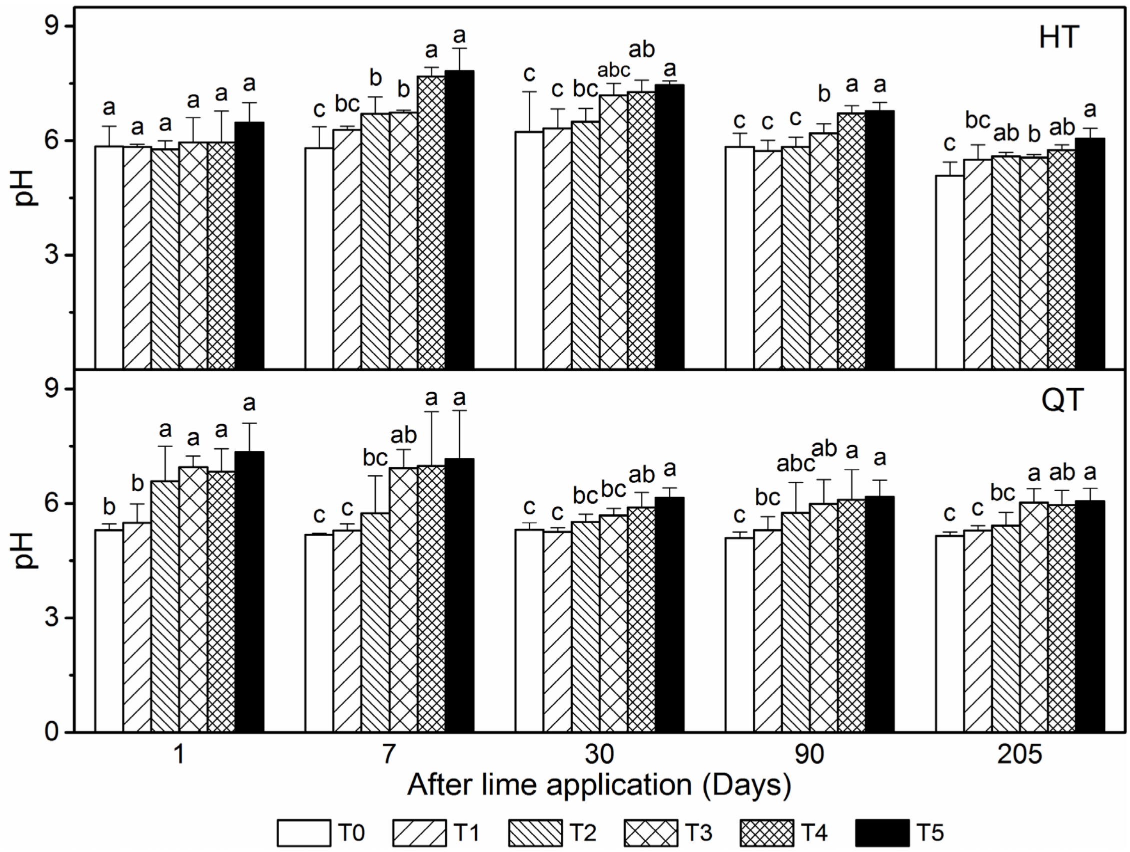

FIGURE 3. Soil pH of paddy field limed with different rates during periods of double season rice growth at Hecun town site (HT) and Qinghu town site (QT). (error bars represent the % standard deviation, n=3; different letter above bars indicate a significant difference at $P< 0.05$ from each other at identical sampling day as determined by LSD method)

THE DYNAMICS OF SOIL OM, TN AND AVAILABLE-P AFFECTED BY LIME APPLICATION

The organic matter contents, total and available nutrients (OM, TN and Avai-P) of soil treated with various rates of massive burned lime are presented in Figure 4. However, the effect of lime on soil nutrients were differed between HT and QT. For soil organic matter content, appeared to be a raised tendency with increasing lime rates at HT (Figure 4(a)), especially after 7 days of lime application and at early rice harvesting, where the organic matter content in T5 significantly increased by 22.8, 28.7, and 11.9% and by 14.1, 17.3, and 15.8% compared with T0, T1, and T2, respectively. Afterwards, application of lime showed a slight elevation in OM contents but with no significant difference compared to control soil. In contrary, there was a negative correlation between OM and lime rate after 30 days of lime application at QT (Figure 4(b)). The OM in T4 and T5 significantly declined by 10.7 and 11.0% after early rice maturity, and significantly dropped in T3, T4, and T5 treated plots by 8.8, 11.1, and 9.4% at late rice maturity compared to T1, but not significantly change to control. The effect of lime on TN was similar to OM both at HT and QT (Figure 4(c) and 4(d)). At HT, the TN after 7 days of application was significantly increased by 14.0 and 17.9% with T5 treatment as compared to T0 and T1, and by 22.3, 33.8, and 21.8% compared with T0, T1, and T2 after early rice harvesting, respectively. While at QT, they were not significantly affected by liming throughout two growing seasons, although liming significantly decreased the OM.

Available-P in soil varied over time in either of sites (Figure 4(e) and 4(f)). The highest values were observed at 7 days of rice transplanting as a result of fertilizer application, followed by a gradual decrease to lowest value at end of early rice production. However, Figure 4(e) and 4(f) showed that avai-P was positively affected by liming during early rice period. For HT site, the highest avai-P was obtained immediately after 1 day of lime application in T5, and significantly higher than T1 and T2 at HT, but no difference against T0. After 7 days of lime application, the avai-P showed a rising trend with increased lime rates where T5 treatment significantly increased by 36.3 and 28.0% compared with T0 and T1. While at QT, the highest avai-P was observed in T4 and the lowest values in T2 after 7 days of lime application. Afterward to the end of experiment, the avai-P in soil was not affected by liming.

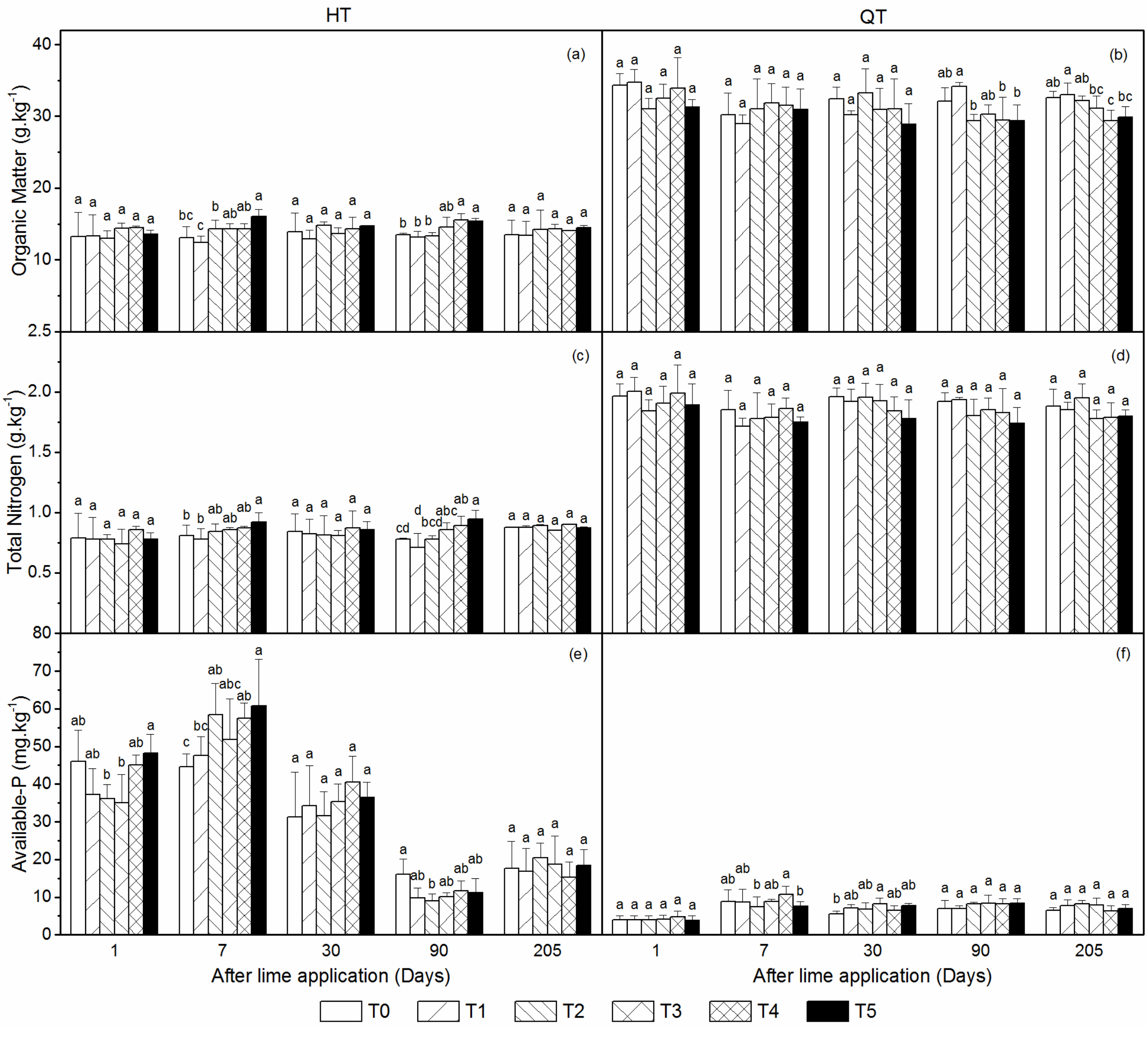

FIGURE 4. Soil nutrients of paddy field limed with different rates during periods of double season rice growth at Hecun town site (HT) and Qinghu town site (QT). (error bars represent the % standard deviation, n=3; different letter above bars indicate a significant difference at *P*< 0.05 from each other at identical sampling day as determined by LSD method)

THE EFFECT OF LIME RATES ON RICE YIELDS

The difference in rice yield caused by different lime rates was noticed at HT and QT (Table 2). The results showed a gradual increase in grain yield with increasing lime rates, followed by a slow decrease in yield with further rise in lime rates. The highest yield of early rice was observed with lime rate of 750 kg/ha at HT although without statistical difference between treatments, while that was in lime rate of 3750 kg/ha at QT with significantly higher than lime rate of 750 kg/ha. As regards with late rice, the maximum yield was obtained in T3 with lime rate of 2250 kg/ha at HT and in T4 with lime rate of 3000 kg/ha at QT, respectively, and both significantly higher than treatments with lime rate below 750 kg/ha. This indicated that either massive quicklime or powdered hydrated lime was beneficial to rice production when applied in proper rates.

TABLE 2. Rice grain yields of different treatments at two localities (kg/ha). Numbers in parentheses denote the SD of the mean (n=3)

Application rates (kg/ha)	HT		QT	
	Early rice	Late rice	Early rice	Late rice
0	6714.5 (568.2)^{a}	8559.6 (431.6)^{c}	7483.7 (744.0)^{ab}	8676.2 (316.3)^{b}
750	6776.0 (350.6)^{a}	8673.4 (489.9)^{bc}	7261.7 (173.4)^{b}	8690.2 (434.9)^{b}
1500	6616.2 (665.4)^{a}	8842.0 (341.1)^{abc}	7453.6 (951.0)^{ab}	8895.3 (343.4)^{ab}
2250	6226.7 (396.6)^{a}	9274.4 (587.3)^{a}	7634.6 (510.3)^{ab}	8991.0 (530.3)^{ab}
3000	6529.0 (725.0)^{a}	9058.6 (244.4)^{ab}	7663.3 (522.4)^{ab}	9042.0 (342.9)^{a}
3750	6544.8 (227.7)^{a}	8962.0 (799.3)^{abc}	7915.1 (692.7)^{a}	8845.3 (666.4)^{ab}

The different letters followed by yield means within a column indicate a significant difference (P< 0.05) between treatments as determined by LSD method

DISCUSSION

IMPROVED LIMING TECHNOLOGY AND TRADITIONAL LIMING METHOD

As an efficient ameliorating practice for agricultural acidic soils, liming has been widely used over the world, and its beneficial effects also have been well established in agricultural production (Arshad et al. 2012; Shamshuddin et al. 2016; Tang et al. 2003). However, many farmers are reluctant to follow these studies particularly due to its unfavorable economic benefits, especially in terms of time and labor, pollution to environment and caused harm to skin of operators as using powder lime material (such as hydrated lime and ground stone lime). In 2016, a farmer lived in QT, Jiangshan City, owned about 100 ha paddy fields was recommended to use massive quicklime instead of traditional hydrated lime for amending acidic soils. It successfully achieved the expected results in about 16 ha of tentatively fields, with high yield of rice without generating flying dusts or corresponding adverse impacts. The study showed that the similar ameliorating effects for soil pH was obtained by lime application with massive quicklime and hydrated lime, and rice yield also not any difference between these two lime materials (Table 3 & Figure 2). The similar ameliorating effects for soil pH with the same applying rates between two lime types maybe the facts that the massive quicklime (CaO) released more OH^+ during reaction with water, but contained more impurity compared to hydrated lime ($Ca(OH)_2$). Furthermore, compared to hydrated lime, the labor cost of applying massive quicklime investigated from eight local farmers in 2018 were cheaper by ¥ 90 yuan/ha (Table 3). The powdered hydrated lime (TP) raised the soil pH to peak earlier than do the quicklime due to finer lime material with the neutralization reactions of powdered hydrated lime with soil acidity were more rapidly than did the massive burned lime. This result is consistent with previous researches (Álvarez et al. 2010, 2009), they also found the application of finer liming materials increased the soil pH more rapidly than coarser materials in a magnesium limestone test with different particle size. A slightly increase of pH observed in TM treatment within 7 days after application may be resulted from incomplete mixing yet as incorporating lime into soil by manually turning over. However, this is not a problem because lime was mixed into soil thoroughly by ploughing with large sized tractor in practical agriculture. These evidences confirmed that the massive quicklime applying into agricultural soil is an impeccable technology with clean, practical, economic and environmentally friendly.

TABLE 3. Comparison between two methods for effect of applying lime. TP, Powdered hydrated lime; TM, Massive quicklime. Numbers in parentheses denote the SD of the mean (n=3)

Application methods	Shape	Environmental pollution	Skin -damaging	Labour cost (¥/hm^2)	Rice yields (kg/hm^2)	Results of reducing acids
TP	Powdered hydrated lime	Air pollution	Great	300	7245.0 (261.8)[a]	Fine
TM	Massive quicklime	Little or no pollution	Little	210	7065.0 (474.3)[a]	Fine

The different letters followed by yield means within a column indicate a significant difference (P< 0.05) between treatments as determined by LSD method

RESPONSE OF SOIL PROPERTIES TO VARIOUS RATES OF LIME

It is widely known that the applying of limes possessed a remarkable effect for acidified soil. After two seasons of rice growing in present tests, the increase rate of soil pH amended with high lime was clearly higher than the low lime treatments compared to the control. According to Edwards and Beegle (1988), for purposes of normal agronomic soil recommendations, pH changes less than 0.5 units does usually not consider to be 'practical' pH changes with respect to soil management practices, sampling and analytical uncertainly. This study showed the quicklime rates of <1500 Mg/ha at HT or <2250 Mg/ha at QT improved the soil-pH with a value of less than 0.5 unit compared with that of before treatment, indicating these rates of quicklime were insufficient to mitigate soil acidity. Additionally, some differences were noted in pH changes between two experiment sites. QT soil was slightly more responsive with lime (rising and declining more rapidly) but less change extent than HT soil. These variations reflected different soil type and its properties, with greater sand content and higher OM in QT soil than in HT soil (Table 1). The soil contained high clay content or OM possessed high pH buffer capacity (Li et al. 2018; Wang et al. 2016). The increase of pH in control soil during the periods of rice growth because the pH value in submerged paddy soils tends to converge to neutrality irrespective of initial pH (McBride 1994).

Considering different soil characteristics, the influences of OM, TN and avai-P in two site soils by liming seem toward opposing tendency with an increase for HT soil but slightly decline for QT soil, respectively, especially at the stage of after fertilizing (Figure 4). Paradelo et al. (2015) reviewed numerous previous researches and concluded that increasing or dropping by liming in soil organic matter depended on three factors: The first one is enhancing mineralization via promoting activity of soil biological with pH rise, and lead to a decline in OM. The second one is reducing decay through increasing the stability of clay assemblages and clay-organic matter bonds, resulting an increase of OM protection. Finally, a potential increase of C inputs due to enhancing plant biomass as liming ameliorates soil conditions to plant growth. Compared to unlimed soil, the increase of organic matter by 3.8-12.3% in HT with rates of applying lime > 1500 kg/ha, possible high silt-clay soil is advantageous to forming more stable structure and non-favourite to biological activity, which most resisted to degradation of OM (Filho et al. 2018; Mavi et al. 2018).

Whereas, a decrease by 0.4-3.9% in QT soil maybe as a result of contrary conditions due to high sand soil that accelerated microbial activity and thus decomposition rate in OM (Creamer et al. 2016; Kiem & Kandeler 1997; Sugihara et al. 2010). Furthermore, the higher organic matter in QT soil maybe is another important factor enhancing degradation due to providing substantially adequate C for biological reproduction (Jiao et al. 2011). Whereas the low OM in HT soil showed that a decrease in SOC mineralization following liming was due to increased microbial C-use efficiency (Grover et al. 2017). Regarding effects of TN affected by lime, there is a similar tendency of changes of organic matter with an increase in HT soil as lime applying rates rise, but a drop in QT soil. The TN drops in QT corresponding to OM can be explained by previous studies. Teutscherova et al. (2016) and Zhuang et al. (2016) suggested that liming can significantly enhance soil nitrification, especially for nitrogen fertilizer (most in the form of ammonium (NH_4^+) or NH_4^+ based compounds) which can be rapidly converted into nitrate (NO_3^-) via nitrification. This process maybe caused N losses via NO_3^- leaching or nitrous oxide (N_2O) emissions when cumulative mineralized nitrogen (NH_4^+ + NO_3^-) greatly exceed crops uptake. Additionally, in acidic sandy soil, liming also significantly increased N_2 emissions as a result of the significant increase in denitrification (Senbayram et al. 2019).

Phosphorus (P), an essential macro-nutrient for crop growth, its availability in agricultural soils must be assured adequately to avoid being a yield-limiting factor in crop production. In general, most of phosphorus is presented as Al or Fe oxides, hydroxides, allophane and kaolinite, bounded as calcium-phosphates, or presented in organic forms (Simonsson et al. 2018; Wijanarko & Taufiq 2016). Its availability is highly pH-dependent, usually decreasing avai-P with increasing pH due to the formation of less soluble Ca-phosphate, whereas increasing with pH dropping as result of release of precipitation (Fageria & Baligar 1999; Wijanarko & Taufiq 2016). However, the decrease of avai-P in soils with lower pH might be owed to precipitation as highly insoluble Fe and Al phosphates (Fageria & Baligar 1999; Park & Ro 2018), and vice versa, enhancing pH may accelerate the mineralization of organic-P, dissolution of Fe-P and Al-P complexes, thus increasing avai-P (Arshad et al. 2012; Karaivazoglou et al. 2007; Li et al. 2018). Hence, the mechanism of avai-P changes occurred after lime application may depend on the various soil characteristics. Controversy surrounded the effects of liming on avai-P in soils with some previous studies, reporting a negative (Blomquist et al. 2017; Shamshuddin et al. 2016) and others a positive relationship (Arshad et al. 2012; Li et al. 2018; Simonsson et al. 2018). In this study, a similar increase in avai-P due to lime application during most cases of early rice growth, as happened in the previous study, may cause some solubilization of P from Fe-P and Al-P complexes, as well as release from mineralized organic-P. Largely possible, increasing avai-P is originated from solubilizing in Fe-P or/and Al-P complexes at HT, while from OM degradation at QT, corresponding increase of low OM and drop of high one by liming. Eventually, a noteworthy concern should be considered that fresh water eutrophication caused by losses of excessive soluble nutrients (mainly N and P) (Harun et al. 2021; Teutscherova et al. 2017; Tucher et al. 2018; Zhuang et al. 2016), and deficiency in certain elements when applying quicklime to agricultural soil (Holland et al. 2019; Karaivazoglou et al. 2007).

RESPONSE OF RICE YIELDS TO VARIOUS RATES OF LIME

An adequate nutrient availability in soils is crucial to crop growth (Bhardwaj et al. 2020; Saha et al. 2019), and the increase in crops yield benefited from lime application due to improving the soil nutrient are well reported by previous researchers. For instance, a 3 years' field experiments conducted by Tang et al. (2003) in Wongan Hills, Western Australia found wheat yield increased by 23-24% and barley shoot biomass increased by 45-70% in the limed soils compared with unlimed soils. On an Albright silt loam soil in Canadian, Arshad et al. (2012) noted liming with a calcium carbonate rate of 6.72 Mg/ha significantly increased grain yields of barley, canola and pea by 38, 31, and 49%, respectively, compared with control. In paddy field, rice grain yield was also significantly enhanced by a maximum of 11.1% for first rice and 47.1% for second rice following lime application with different rates (Shamshuddin et al. 2016). The present study showed that applying lime significantly increased the rice yield in strongly acidic paddy field (soil pH ≈ 5.1) at HT and QT, while no influence in weakly acidic field (soil pH ≈ 6.0) at GT (Table 2). This result was in agreement with the conclusion studied by Paganiand and Mallarino (2015), they considered that no increase in soybean yield resulted from liming in soil with pH > 6.5. Meanwhile, the effect of lime application was higher in late rice than in early rice, i.e. delayed effectiveness may be due to insufficient time for lime application to fully mixing with soil, as reported by previous studies (Blomquist et al. 2017; Edwards & Beegle 1988; Shamshuddin et al. 2016). However, the liming efficiency in rice yield increase is not as great as reporting by other researchers. The main cause maybe is various crops species with different tolerance to soil acidity and sensitivity to soil pH. Among the most (farmed) crops, rice is the most tolerant to soil acidity with suitable pH of 6.0 and can grow well even though water pH is below 5 (Fageria &

Baligar 1999; Shamshuddin at al. 2016). Furthermore, three above-mentioned tests all performed on serious acidic soils (pH < 5.0), where multiple element toxicities such as Al, Mn, Fe (Álvarez et al. 2009; Karaivazoglou et al. 2007; Li et al. 2018) and nutrient deficiencies such as Ca, Mg, N, P, B, etc (Li et al. 2018; Shamshuddin et al. 2016) most probably occurred. Thus, remarkable and positive impacts are gained easily by eliminating those limiting-factors with lime amending. In this study, the soils maintained pH of above 5.0 throughout the double season rice cycle, indicating responsible for little increase of late rice yield is more likely to be other factors associated with improving soil porous system (Ferreira et al. 2018), nutrient balances and crop uptake (Bailey 1995; Karaivazoglou et al. 2007; Seth et al. 2018), and biological activity (Alvarez et al. 2010; Kiem & Kandeler 1997). Additionally, the data obtained from late rice yields demonstrated lime application rates of > 2250 kg/ha to high clay soils or > 3000 kg/ha to high sand soils are regarded as a somewhat harmful effect for rice growth in paddy field. However, over-liming of agricultural soils is also known to reduce soil productivity through a variety of complex processes ranging from restricted nutrient availability and to increased element toxicity or disease (Pagani & Mallarino 2015). Consequently, in practical agriculture production, it is imperative to define correctly lime requirements for optimum soil pH and further crops growing in acidic soil.

Conclusion

The ameliorating effectiveness of acidic paddy soil by massive quicklime and powered hydrated lime application was compared in the present work. The results showed that similar ameliorating effects on agricultural acidic soil between massive quicklime and powered hydrated lime. The improved method by applying massive quicklime is the most promising method with clean, practical, economic and environmentally friendly approach. Further experiments also showed that the high dosages of massive quicklime application significantly increased soil nutrients, such organic matter, total nitrogen and available phosphorus at Hecun town with a clay loam soil, while appeared to be a decline tendency at Qinghu town with a sandy loam soil. A gradual increase in grain yield with increasing dose of massive quicklime, followed by a slow decrease in yield with further rise in lime rates was observed but with different response at two sites. Conclusively, application of massive quicklime as an economic and environmentally-friendly technique can be more acceptable by farmers to correct acidic soils worldwide. The optimal rates of massive quicklime for rice cultivation on acidic paddy field were 1500-2250 kg/ha for clay soil and 2250-3000 kg/ha for sandy soil, respectively.

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The Agricultural Technique Popularization Centre of Jiangshan City
Jiangshan, Zhejiang, 324100
China

*Corresponding author; email: man_0034@163.com

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