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RESEARCH ARTICLE

Liming for the management of submerged aquatic weeds in rice

P. Prameela*, Savitha Antony and S.G. Gowtham

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ABSTRACT

Submerged aquatic flora are problem weeds, not only in aquatic bodies but also in wetland rice. An experiment was conducted at Kerala Agricultural University to assess the efficacy of different liming materials to manage submerged aquatic weeds in an eco-friendly manner. Preliminary studies were conducted in tanks containing *Hydrilla* spp., *Najas* spp. and *Utricularia* spp. Quicklime was effective among the three liming materials tested, while calcium carbonate and dolomite were ineffective. The increase in dose of quick lime from 2, 4, 6, 8 and 10 g/L of water in the tank resulted in a significant and rapid decline in chlorophyll content of weeds. Complete mortality of weeds occurred within four weeks of liming. In rice fields with acid soil, more than 80% weed control was observed with application of quicklime 300g/m^2 or above, which resulted in rice grain yield comparable to hand weeded plot. Rapid fluctuations in various water quality parameters were observed, including pH, electrical conductivity (EC), acidity, alkalinity, carbonate, bicarbonate, nitrate, and hardness; but the values stabilized two weeks after application. The study revealed that the application of quicklime serves as an effective method for managing submerged freshwater aquatic weeds in rice.

Keywords: Quicklime, *Hydrilla*, *Utricularia*, *Najas*, Rice, Submerged aquatic weeds, Water quality

INTRODUCTION

In India, the proliferation of submerged aquatic weeds poses a major challenge in freshwater ecosystems including rivers, canals, ponds, and irrigation systems (Sushilkumar 2011, Kawade *et al.* 2023). Weeds including *Cabomba furcata*, *Lymnophylla heterophylla*, *Hydrilla verticillata*, *Najas* spp., and *Utricularia* spp. obstruct water flow, reduce water availability, and disturb ecological balance. Infestation in the Chambal irrigation canals reduced water flow by 40–50% (Holm *et al.* 1991). The aquatic weeds were dominant in rice fields, in the initial stages of crop growth, when rice in cultivated under intensive wet tillage (puddling) conditions mainly in lowland and medium lowland areas where water from ponds were continuously available (Rao *et al.* 2017). In rice fields of Kerala, where such conditions exist, *Najas* spp. and *Utricularia* spp. are often problem weeds in transplanted rice, due to the availability of conducive light and space during the early growth phase (AICRP 2020). Physical removal, though commonly practiced, is often ineffective due to rapid regeneration of biomass. Chemical methods including bispyribac-sodium, glyphosate, 2,4-D, penoxsulam, and endothall have been evaluated with varying efficacy elsewhere (Durborow 2014). Endothall reduced *Cabomba* spp. biomass by 67% within four weeks at 5 mg/L (Hofstra *et al.* 2021). However, herbicides are not registered, currently, in India for submerged aquatic weed management.

As alternatives to synthetic herbicides, liming agents such as calcium hydroxide [$Ca(OH)_2$] and quicklime (CaO) have been reported effective by altering water pH and nutrient availability. Murphy and Prepas (1990) demonstrated that $Ca(OH)_2$ 250 mg/L reduced chlorophyll from 0.75 mg/L to <0.25 mg/L in hard water lakes, outperforming $CaCO_3$. Similarly, Zhang and Prepas (1996) reported >50% reduction in chlorophyll within 20 days at 25–87 mg/L $Ca(OH)_2$. In mesocosm and canal studies, Chambers *et al.* (2001) observed suppression of *Potamogeton pectinatus* with 200–210 mg/L $Ca(OH)_2$, while Reedyk *et al.* (2001) documented ~80% biomass reduction of *Ceratophyllum demersum* and *Potamogeton* spp. at 74–107 mg/L $Ca(OH)_2$. These findings emphasise the potential of liming materials as viable tools for submerged aquatic weed management. Thus, this experiment was conducted with an objective to assess the efficacy of using different liming materials to manage submerged aquatic weeds in the rice ecosystem of Kerala, India.

AICRP on Weed Management, Department of Agronomy, College of Agriculture, Thrissur, Kerala 680656, India

* Corresponding author email: prameela.p@kau.in

MATERIALS AND METHODS

The experiments were conducted during the period from 2020 to 2024 at the College of Agriculture, Thrissur, Kerala and farmers' field at various locations. The experiment consisted of two tank studies and multi-location field experiments. Pilot tank studies were conducted to identify the effective liming material, dose and impact on water quality, in tanks of 50 L capacity. After placing a bottom layer of 3 kg soil, the tanks were filled with 30 L of fresh water and a uniform quantity of fresh weeds weighing 300g was placed in each tank. To identify the effective liming material for controlling submerged weeds, varied doses of three liming materials such as quick lime (CaO), calcium carbonate ($CaCO_3$) and dolomite ($CaCO_3$ and $MgCO_3$) at varied doses ranging from 0.5 g/ L to 20 g/ L of water in the tank were administered. The neutralizing values of these amendments were 125, 100 and 95, respectively.

Standardisation of dose of quicklime

As quicklime was the only effective liming material, the second tank study was conducted to standardize the dose of quicklime. The treatments consisted of 2, 4, 6, 8, and 10 g of CaO per liter of water in the tank. Untreated tanks with weed (UTC+W) and without weed (UTC-W) were also maintained for effective comparison. The complete randomized block design was used with three replications.

The pH and electrical conductivity (EC) of water were assessed at 2 hours after application (HAA) and at, 1, 7, 15, 21 and 30 days after application (DAA). Other water quality parameters like carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), total alkalinity, total hardness, acidity were estimated at 15 days interval, and nitrate, phosphate, calcium, magnesium, iron and manganese were estimated at 30 DAA

The extent of weed control was recorded based on visual assessment at 14, 21, and 30 DAA and expressed as percentage control (**Figure 1**). The percentage control of weeds, chlorophyll degradation, and a combination of both these parameters were used for assessing weed control efficiency. Regrowth of weeds was observed at 30 DAA. Phytotoxicity rating was given based on the standard scoring of 0-5 scale (0 - no control, 1 - slight control, 2 - moderate control, 3 - good control, 4 – very good control, 5 - complete control) (Thomas and Abraham 2007). The data were statistically analyzed using ANOVA, and the significant differences between treatments were studied using TUKEY's test.

The field experiments were conducted at three locations (Alathur, Pattambi and Pukottukavu) in Palakkad district of Kerala. The submerged aquatic weed infestations in transplanted rice occurred at 25-30 day after rice establishment. *Najas* spp, and *Utricularia* spp. were the dominant weeds and all other weeds of rice were absent. Treatments were applied in plots of 5 x 4m. The average rice stand was 20-25 hills/m^2. The variety of rice was Uma (medium duration variety, 125-130 days). The soil pH of experimental sites ranged from 5.06 - 5.78. Quick lime 120, 180, 240, 300 to 420 g/m^2 was broadcasted, as per the treatments tested. The dosages starting from 120 g/m^2 were tested since the infestations were observed even in fields applied with recommended doses of 600 kg/ha (60 g/m^2) lime (KAU 2024). The doses were fixed based on FAO recommendations for pond liming (2000-4000 kg/ha) (FAO 2022). Change in soil pH at 10 days after application (DAA), percent weed control and rice grain yield were recorded.

RESULTS AND DISCUSSION

Comparative efficacy of liming materials

The quick lime alone was effective against the submerged weeds. Calcite and dolomite did not cause any phytotoxic effect and failed to control submerged weeds which might be due to the fact that the reaction between calcite and dolomite with water is an endothermic process. In addition, the reaction of calcium carbonate and magnesium carbonate with water is very slow. Calcium carbonate is insoluble in water and exhibits solubility in CO_2 saturated water, producing calcium bicarbonate, a weak base that dissolves in water. This could be the reason for its less detrimental effect on weeds. Similar is the case with dolomite also which yields bicarbonates of magnesium and calcium which yields weak base on its dissolution in CO_2 saturated water. However, when CaO reacts with water, it undergoes an exothermic process, producing $Ca(OH)_2$ which is a strong base which resulted in cell damage of submerged weeds followed by decay.

By 14 days after application percent weed control ranged from 80% even when CaO 2g/L was applied, to more than 90% with higher rates. By 21 DAA complete control was observed at all doses except the lower dose of 2g/L where it took a longer period of 30 days (**Figure 1**). This is clear from the observations on chlorophyll content (**Figure 2**) where the initial content was 1.67 mg/L. Notable decline in chlorophyll content was observed immediately after application. Chlorophyll content decreased to 0.08 mg/g by 7 days due to the highly corrosive action of calcium oxide in water. More than

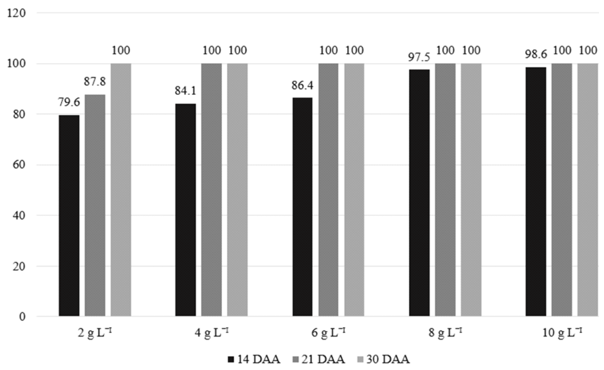

Figure 1. Percentage control of weeds, based on visual phytotoxicity and chlorophyll content, with the application of different doses of quicklime (CaO)

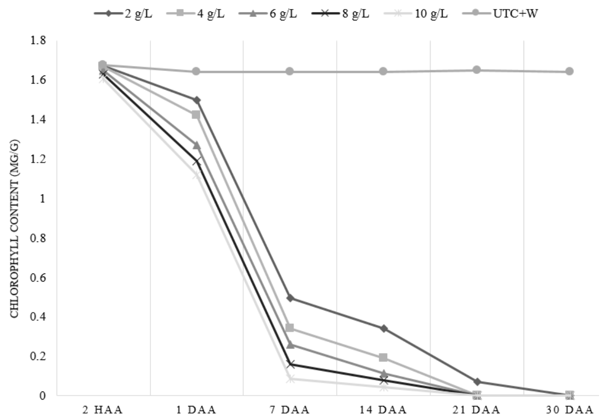

Figure 2. Total chlorophyll content of weeds as affected by different doses of quicklime (CaO)

50% reduction in chlorophyll content was observed at higher doses after 14 days of liming. By 30 days, complete chlorophyll degradation and weed control was observed in all the quicklime applied tanks.

The degradation of chlorophyll content of weeds occurred due to the vigorous exothermic reaction between calcium oxide and water. When calcium oxide reacts with water, it produces a solution of calcium hydroxide, which is a strong base, leading to cell damage. The addition of quicklime alters the inorganic carbon chemistry within soft water systems, limiting the availability of free CO_2 for the photosynthesis of submerged aquatic macrophytes (James 2011). Pond liming has the potential to shift the equilibrium of inorganic carbon towards bicarbonate dominance by transiently increasing the pH of soft water.

In addition to altering CO_2 chemistry, the rise in pH hindered oxygen within mesophyll cells and decreased the activity of ribulose-1,5-bisphosphate carboxylase (RuBP), consequently affecting photosynthesis and photorespiration of plant cells (Servaites and Ogren 1977). The complete weed control with quicklime application in all the tanks by 30 days can be attributed to the above reasons. Weeds in the untreated tanks exhibited consistent chlorophyll content, and their growth continued unabated.

Water quality parameters like pH, EC, carbonates, bicarbonates, alkalinity, total hardness, calcium, increased with increasing dose of quicklime. The values remained higher than the initial and the contents decreased over time (up to 30 days). The content nitrate, total nitrogen, phosphates, magnesium, iron, and manganese decreased with increasing dose of quicklime.

Significant increase in pH and EC was noticed after quicklime application (**Table 1** and **2**). pH increased till 2nd day in all the treatments, ranging from 10.57 to 11.44. There was a drastic increase in EC up to 14 days ranging from 0.66 dS/m to 3.56 dS/m. However, the pH and EC values remained higher than the untreated check in the range of 8.82 to 9.0 and 0.56 dS/m to 1.83 dS/m throughout the post-treatment period (30 days).

The trend in decrease of pH is the effect of organic matter content, Cation Exchange Capacity (CEC) and buffering capacity of the soil. As suggested by Panda *et al.* (2012), the pH of the solution depends on the CEC and buffering capacity of the soil and organic matter. Soil organic matter contains reactive carboxylic and phenolic groups that behaves as weak acids and they dissociate releasing H^+ ions which could increase the acidity of the solution. Liming could facilitate easy degradation of organic matter releasing organic acids, phenols, and H^+ ions.

Table 1. Effect of different quicklime doses on pH of water at different days after application (DAA)

Treatment	2 HAA	1 DAA	7 DAA	14 DAA	21 DAA	30 DAA
Quicklime 2 g/L	9.66^{d}	10.57^{d}	9.62^{e}	9.31^{e}	9.12^{c}	8.82^{d}
Quicklime 4 g/L	9.80^{cd}	10.88^{c}	9.83^{d}	9.57^{d}	9.18^{c}	8.95^{cd}
Quicklime 6 g/L	9.90^{c}	11.08^{b}	10.31^{c}	10.04^{c}	9.48^{b}	9.06^{c}
Quicklime 8 g/L	10.22^{b}	11.30^{a}	10.92^{b}	10.65^{b}	9.99^{a}	9.37^{b}
Quicklime 10 g/L	10.50^{a}	11.44^{a}	11.24^{a}	10.95^{a}	10.18^{a}	9.71^{a}
Untreated tanks with weeds	7.42^{e}	7.45^{e}	7.51^{f}	7.51^{f}	7.59^{d}	7.61^{e}
Untreated tanks without weeds	7.30^{e}	7.33^{e}	7.36^{f}	7.34^{f}	7.37^{e}	7.36^{f}

HAA - hours after application

Carbonates, bicarbonates, alkalinity, total hardness increased by 15 days, thereafter gradually decreased (**Figure 3**). Bicarbonates, total hardness, and alkalinity content ranged from 1.33 meq/L to 5.0 meq/L, 154.67 meq/L to 348.67 meq/L and 70 mg/L to 226.66 mg/L, respectively by 30 days. It can be attributed to the buffering capacity of water and the reaction of quicklime in water. The hydroxide ions (OH^-) formed in the solution cause immediate increase in pH and EC of water and rapidly react with CO_2, forming carbonates and bicarbonates. This resulted in increase in the alkalinity and total hardness. However, with time, due to gradual release of CO_2 from the solution, the carbonates and bicarbonates reached equilibrium in water and thereby alkalinity and total hardness got decreased by 30 days of lime application.

By 30 days after liming, nutrient content in water decreased with the increasing dose of quicklime (**Table 3**). Nitrate content decreased from initial value of 4.70 mg/L to 2.92 mg/L and 1.04 mg/L. This might be due to denitrification losses. Under high pH and alkalinity, the nitrate will be converted to nitrogen gas while ammonium (NH_4^+) will get reduced to ammonia (NH_3) which will be lost through volatilization.

Similarly, total nitrogen decreased from 6.60 mg/L to 1.19 mg/L and phosphate from 59.28 mg/L to 6.75 mg/L. Phosphorus precipitated as calcium phosphate and thereby decreased the phosphate concentration in solution. Magnesium, iron, and manganese content of water decreased by 27, 39, and 39%, respectively after 30 days in higher doses of quicklime application (10 g/L). Deb *et al*. (2012) reported that the availability of iron and manganese reduced at higher pH as the oxidized forms of iron (Fe^{3+}) and manganese (Mn^{3+}) are less soluble. The higher pH of the soil solution facilitated the oxidation of iron and manganese which are less soluble causing decreased availability of these metal cations.

Table 2. Effect of quicklime doses on EC of water at different days after application (DAA)

Treatment	2 HAA	1 DAA	7 DAA	14 DAA	21 DAA	30 DAA
Quicklime 2 g/L	0.25[d]	0.52[d]	0.54[e]	0.66[d]	0.62[d]	0.56[e]
Quicklime 4 g/L	0.27[cd]	0.66[cd]	0.80[d]	0.77[d]	0.71[cd]	0.65[d]
Quicklime 6 g/L	0.29[bc]	0.79[c]	1.24[c]	1.40[c]	0.82[c]	0.84[c]
Quicklime 8 g/L	0.32[b]	1.21[b]	2.36[b]	2.03[b]	1.36[b]	0.93[b]
Quicklime 10 g/L	0.65[a]	2.03[a]	2.63[a]	3.56[a]	2.93[a]	1.83[a]
Untreated tanks with weeds	0.13[e]	0.14[e]	0.13[f]	0.14[e]	0.14[e]	0.14[f]
Untreated tanks without weeds	0.12[e]	0.13[e]	0.12[f]	0.13[e]	0.13[e]	0.13[f]

HAA - hours after application, untreated tanks with weeds (UTC+W) and without weeds (UTC-W)

Table 3. Effect of different doses of quicklime on water quality parameters (mg/L) at 30 days after liming

Treatment	Nitrate	Magnesium	Iron	Manganese	Total nitrogen	Phosphate
Quicklime 2 g/L	2.92[b]	3.00[a]	0.247[ab]	0.219[a]	3.89[b]	59.28[a]
Quicklime 4 g/L	2.40[c]	2.83[b]	0.223[bc]	0.175[b]	3.15[c]	44.04[b]
Quicklime 6 g/L	1.77[d]	2.62[c]	0.210[cd]	0.146[bc]	2.26[d]	30.48[c]
Quicklime 8 g/L	1.35[de]	2.49[c]	0.197[cd]	0.123[cd]	1.69[e]	18.63[cd]
Quicklime 10 g/L	1.04[ef]	2.28[d]	0.163[e]	0.105[d]	1.19[f]	6.75[d]
Untreated tanks with weeds	3.76[a]	3.12[a]	0.273[a]	0.25[a]	5.10[a]	71.16[a]
Untreated tanks without weeds	0.62[f]	1.10[e]	0.197[cd]	0.058[e]	2.41[d]	25.41[c]
Pre-treatment values	4.70	3.55	0.38	0.43	6.60	81.33

Table 4. The extent of *Najas* spp. and *Utricularia* spp. control as affected by broadcasting of different doses of quicklime in wetland transplanted rice

Treatment	Extent of control (%)				
	Location- Alathur *Season* – I crop *Weed- Najas*	*Location*- Pattambi *Season* – II crop *Weed- Najas*	*Location*- Pattambi *Season* – II crop *Weed- Utricularia*	*Location*- Pukottukavu *Season* – II crop *Weed- Utricularia*	Pooled
Broadcasted quicklime 420 g/m^2	76.67	93.33	90.00	83.33	86.67
Broadcasted quicklime 300 g/m^2	73.33	86.67	83.33	80.00	81.11
Broadcasted quicklime 240 g/m^2	56.67	66.67	63.33	56.67	62.22
Broadcasted quicklime 180 g/m^2	23.33	33.33	30.00	33.33	28.89
Broadcasted quicklime 120 g/m^2	16.67	20.00	13.33	23.33	16.67
Untreated	-	-	-	-	
LSD(p=0.05)	5.95	11.66	10.31	10.60	

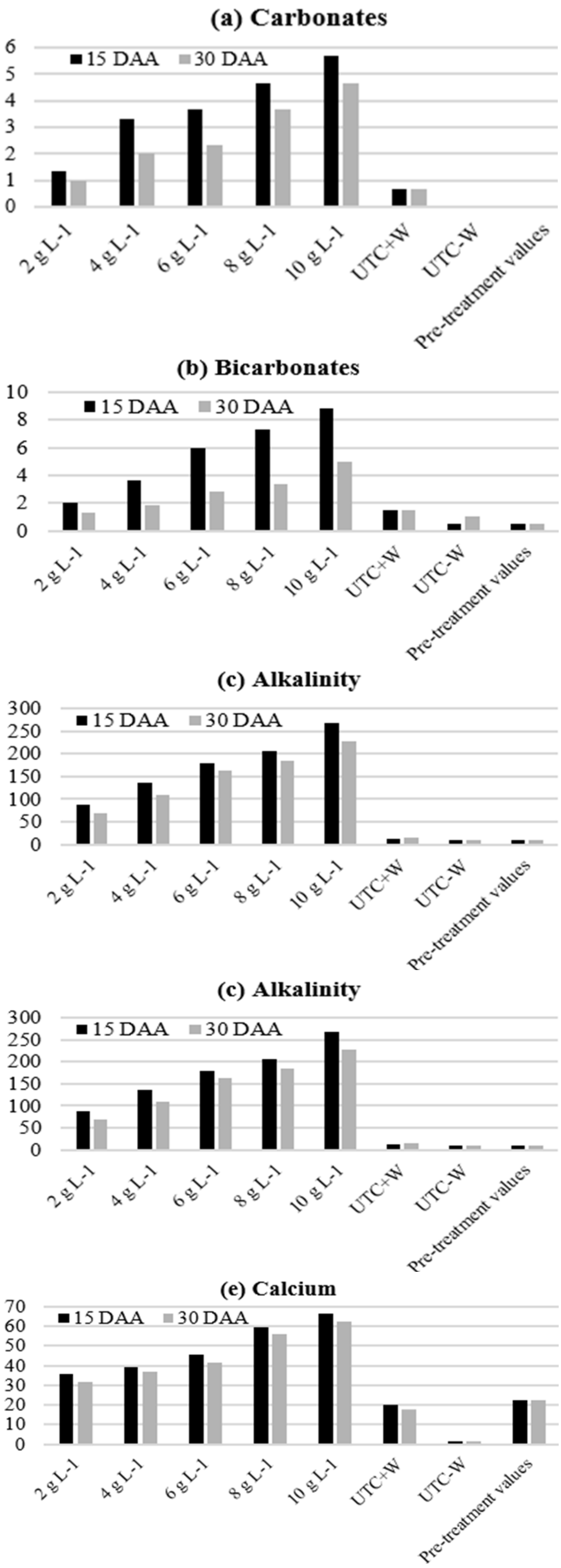

Figure 3. Variations in (a) carbonates, (b) bicarbonates, (c) alkalinity, and (d) total hardness and calcium (e) after 15 and 30 days after application of quicklime at different doses. (UTC+W = untreated tanks with weeds; UTC-W = untreated tanks without weeds)

The drastic reduction in nutrient contents can also be explained based on the coagulation and flocculation property of liming materials. Generally, the efficiency of a coagulant is pH dependent. Alkalinity plays a crucial role in supplying anions like hydroxide for the formation of insoluble compounds, facilitating their precipitation. In the current study, the application of quicklime at a higher dose led to twelvefold increase in alkalinity and pH by 2.0 units, persisting even one month after application. In addition to the pH dependent reduction in zeta potential (Lu and Gao 2010), the hydroxide ions formed after CaO application might have reacted with mineral ions and resulted in the formation of insoluble compounds like magnesium hydroxide, iron hydroxide, and manganese hydroxide which favoured the precipitation of these nutrients into the soil sediments.

Among various submerged aquatic weeds, *Najas* spp. and *Utricularia* spp. infestations are reported in rice fields with poor drainage. The trials were conducted in the *Najas* spp. and *Utricularia* spp. infested fields at three locations during 2021-2024. *Najas* spp. was the dominant weed. Infestation was observed at 25-30 day after rice transplanting and the average rice population was 20-25 hills/m^2.

More than 80 per cent weed control was observed when quick lime was applied at the rate of 300 g/m^2 and higher dosage rate (**Table 4**). There was no phytotoxicity to rice even at higher doses of lime. At 10 DAA, the soil pH ranged from 7.01-7.20 at higher doses (420 g/m^2) (**Table 6**). A higher and near neutral soil pH was observed in all the lime applied fields which were at par and significantly higher than the untreated check. There was no significant reduction in rice grain yield due to weed infestation (**Table 5**). This study demonstrated that quicklime (CaO) is a highly effective liming material for the eco-friendly management of submerged aquatic weeds such as *Hydrilla*, *Najas*, and *Utricularia*. Unlike calcium carbonate and dolomite, quicklime significantly reduced chlorophyll content and led to complete weed mortality within four weeks under controlled conditions.

It can be concluded that the infestation of submerged aquatic weeds like *Najas* and *Utricularia* in transplanted paddy, can be satisfactorily managed, in acidic soils, by localized application of quick lime 240-300 g/m^2 and thus, quicklime may serve as a promising and sustainable alternative for integrated weed management in aquatic and wetland transplanted rice ecosystems.

Table 5. Transplanted rice grain yield (t/ha) in submerged aquatic weeds (*Najas* spp. *and Utricularia* spp.) infested fields as affected by broadcasting of different doses of quicklime

Treatment	*Location*- Alathur *Season* – I crop *Weed- Najas*	**Location*- Pattambi *Season* – II crop *Weed- Najas*	**Location*- Pattambi *Season* – II crop *Weed- Utricularia*	*Location*- Pukottukavu *Season* – II crop *Weed- Utricularia*
Broadcasted quicklime 420 g/m^2	4.72	3.69	3.69	4.26
Broadcasted quicklime 300 g/m^2	4.51	3.48	3.48	4.47
Broadcasted quicklime 240 g/m^2	4.87	3.25	3.25	4.58
Broadcasted quicklime 180 g/m^2	4.22	3.57	3.57	4.87
Broadcasted quicklime 120 g/m^2	4.57	3.41	3.41	4.19
Untreated	4.33	3.39	3.39	4.47
LSD(p=0.05)	0.77	0.61	0.61	0.77

**Najas* spp. and *Utricularia* spp. were observed in the same field

Table 6. Change in soil pH 10 days after application of different doses of quicklime

Treatment	*Location*- Alathur *Season* – I crop *Weed- Najas*	**Location*- Pattambi *Season* – II crop *Weed- Najas*	**Location*- Pattambi *Season* – II crop *Weed- Utricularia*	*Location*- Pukottukavu *Season* – II crop *Weed- Utricularia*
Broadcasted quicklime 420 g/m^2	7.20	7.12	7.12	7.01
Broadcasted quicklime 300 g/m^2	6.47	7.64	7.64	6.71
Broadcasted quicklime 240 g/m^2	6.48	7.19	7.19	6.25
Broadcasted quicklime 180 g/m^2	6.57	6.34	6.34	6.07
Broadcasted quicklime 120 g/m^2	6.20	6.07	6.07	5.75
Untreated	5.78	5.54	5.54	5.06
LSD(p=0.05)	1.14	1.19	1.19	1.11

**Najas* and *Utricularia* were observed in the same field

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