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Evaluation of calcium carbide as a soil amendment to improve nitrogen economy of soil and yield of okra

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Abstract

A series of experiments were conducted to evaluate encapsulated calcium carbide (ECC) as a potent source of acetylene (C_2H_2) and its role as a nitrification inhibitor to improve nitrogen economy of soil. Effect of ECC on green pod yield of okra (Hibiscus esculentus L.) was also studied. Laboratory experiment was conducted to monitor the release of acetylene over a period of 15 days from applied ECC. Another laboratory experiment was conducted in plastic beakers to evaluate the role of ECC as a nitrification inhibitor by studying NH_4^+ and NO_3^- contents in the soil after ECC application with and without urea fertilizer. Pot experiment was conducted where recommended dose of P and K fertilizers were used with three levels of nitrogen fertilizer (0, 30 and 60 mg N kg^{-1} soil) as urea. Encapsulated calcium carbide @ 0, 15 and 30 mg kg^{-1} was applied two weeks after germination 6 cm deep in the center of pots. Results of experiments showed consistent increase in the concentration of C_2H_2 from the day first to day 15 while no C_2H_2 was observed in the control. Increase in the concentration of NH_4^+ – N than NO_3^- - N in the ECC treated pots up to 6 weeks period compared to fertilizer alone supported the role of ECC as a nitrification inhibitor. About 32% increase in green pods yield was recorded with the combined application of nitrogen @ 30 and ECC @ 15 mg kg^{-1} soil over recommended dose of fertilizer alone. These findings imply that CaC_2 enhanced green pod yield of okra by improving the nitrogen economy of soil.

Key words: Calcium carbide, acetylene, ammonium, nitrate, green pod, okra

Introduction

Nitrogen fertilizer use efficiency has been hampered in many agricultural systems because of the loss of large amounts of applied nitrogen through leaching of nitrate or by denitrification process during its chemical transformation, which occurs in the soil-plant-water systems. In well-aerated soils, nitrification appears to be the main production mechanism for nitrous oxide, but in poorly aerated, nitrate rich soils significant emissions result from denitrification (Smith and Arah, 1992). Apart from economics, nitrogen loss has serious social implications. The unused fertilizer nitrogen either leaches down the soil bed or enters the atmosphere as gases. Fertilizer nitrogen which leaches down contributes to nitrate pollution of the groundwater. A high nitrate ground water, when used for drinking purposes causes methemoglobinemia, a condition which incapacitates blood haemoglobin to carry oxygen to body cells. Infants are more prone to methemoglobinemia than adults (Azam and Farooq, 2003). Fertilizer nitrogen which enters the atmosphere in gaseous forms mainly comprises ammonia, nitrous oxide and nitric oxide. Saturation of environment with these gases causes destruction of stratospheric ozone layer exposing the biosphere to harmful ultraviolet radiation.

Since ammonia or ammonium producing compounds are the main sources of fertilizer N, maintenance of the applied N in the ammonium form means that less N is lost by leaching and de-nitrification. In order to reduce these losses and increase its use efficiency, added fertilizer N should remain as ammonium ion for a longer period. This can be done by the addition of a nitrification inhibitor with the fertilizer (Sahrawat *et al.,* 1987).

Calcium carbide (CaC_2) acts as a rich source of acetylene (C_2H_2) gas upon its reaction with water. Acetylene is an effective inhibitor of nitrification and denitrification because it inhibits the activity of the ammonia-oxidizing enzyme involved in the nitrification process (Aulakh *et al*., 2001; Randall *et al*., 2001). Reduced rates of nitrification in soil may result in increased N fertilizer use efficiency. Researchers have used CaC_2 as nitrification inhibitor in soil and have reported substantial improvement in N economy (Arshad and Frankenberger, 2002; Thompson, 1996; Aulakh *et al*., 2001; Randall *et al*., 2001; Yaseen *et al*., 2006).

This study was therefore conducted to study calcium carbide as a source of acetylene and its effects on NH_4-N and NO_3-N contents in soil and yield of okra.

Materials and Methods

A series of experiments were conducted in the laboratory and experimental area of the Institute of Soil & Environmental Sciences, University of Agriculture, Faisalabad. The surface soil from 0-30 cm depth was collected from the research area, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. The soil was air-dried, sieved and analyzed for physical and chemical properties. Encapsulated (Gelatin type, Shaoxing Zhongya Capsules Industry Co. Ltd.,

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Zhejiang, China) CaC_2 (27% a.i. CaC_2, Ningxia National Chemical Group Co. Ltd., China) @ 7.5, 15, 30 and 45 mg kg^{-1} soil was placed in the bottom of the Erlenmeyer flask (125 mL) containing 100 g soil at 60% WHC (water holding capacity). The flaks were capped with mini-inert valves and incubated under ambient laboratory conditions (25$\pm$5 °C). Release of C_2H_2 was monitored daily for 15 days. Native C_2H_2 production was also determined in soil not treated with CaC_2. Each treatment was repeated three times. The experiment was repeated twice and data shown in Figure 1 are average of two experiments. The concentration of C_2H_2 gas was determined by gas chromatography (Shimadzu-4600), fitted with a flame ionization detector (FID) and a capillary column (Porapak Q 80-100) operating isothermally under the following conditions: Carrier gas, N_2 (13 mL min^{-1}); H_2 flow rate, 33 mL min^{-1}; air flow rate, 330 mL min^{-1}; sample volume, 1 mL; column temperature, 70 ^oC; detector temperature, 200 ^oC. The C_2H_2 concentrations were determined by comparison with reference standards of C_2H_2 (99.5%) obtained from Matheson (Secancus, NJ)

For NH_4-N and NO_3-N studies, one kg of the same soil used in above experiment was filled in plastic beakers of size 15 cm x 8 cm. Three levels of urea (0, 30, 60 mg N kg^{-1} soil) were uniformly mixed with the soil before filling it into the beakers. Each treatment was repeated three times. This experiment was also repeated twice. Encapsulated CaC_2 @ 0 and 30 mg kg^{-1} soil of the same origin as above was placed 6 cm deep in the center of each beaker so that C_2H_2 gas could uniformly diffuse to all directions. Calcium sulfate equivalent to the amount of calcium in CaC_2 was added in control. Distilled water was used to maintain the soil moisture near field capacity (60% WHC) up to six weeks from the start of experiment. Tops of the beakers were kept open while their sides were wrapped with aluminum foil. The beakers were placed in the laboratory (25$\pm$5 °C). After six weeks, the contents of each beaker were taken out and mixed thoroughly. Moist soil, equivalent to 10 g dry weight, was extracted for 1h with 100 mL of 2M KCl solution, containing 15 μM phenyl mercuric acetate and filtered through whatman No.42 filter papers The filterate was analysed for NH_4^+-N and NO_3^--N contents using Indophenol Blue Method and NO_3-N contents by Modified Griss-Ilosvay Method (Keeney and Nelson, 1982).

A pot experiment was also conducted to see the effect of calcium carbide on green pod production in okra (*Hibiscus esculentus* L.). Earthen pots lined with polyethylene bags were filled with 12.5 kg same soil as mentioned in above experiments. Three levels of urea fertilizer according to 0, 30 and 60 mg N kg^{-1} soil were applied. Phosphorus @ 45 mg kg^{-1} soil as single super phosphate and potassium @ 30 mg kg^{-1} soil as sulfate of potash were also added in all pots including control. All the fertilizers were uniformly mixed with the soil before filling pots. Encapsulated calcium carbide @ 0, 15 and 30 mg kg^{-1} soil was placed 6 cm deep in soil in the center of the pot two weeks after sowing of okra seeds. Calcium sulfate equivalent to the amount of calcium in CaC_2 was added in control. Canal water was applied to keep the moisture level of soil approximately near field capacity throughout the growth period. After 10 weeks, NH_4^+-N and NO_3^--N contents were determined by method described above. Green pod weight of okra was recorded to find out the effect of CaC_2 application on yield. Data were statistically analyzed according to Steel and Torrie (1980).

Results

Results of the laboratory experiment indicated that acetylene release was directly proportional to the level of calcium carbide used. Increase in rate of acetylene emission was observed with increasing the dose of calcium carbide (Figure 1). Initially a burst of acetylene was produced even on the day first and then going on icreasing with time. Initially there was a large difference in acetylene production between 30 and 45 mg kg^{-1} soil application of CaC_2 which decreased with time and after 15 days, almost same acetylene was observed in both levels of CaC_2. There was no acetylene observed under control treatment indicating no indigenous acetylene production in soil.

Effect of encapsulated calcium carbide (ECC) on the oxidation of NH_4 to NO_3 in the soil supplied with and without urea under laboratory conditions is shown in Figure 2. Maximum concentration of NH_4-N (41.2 mg kg^{-1} soil) was noted in CaC_2-amended (30 mg kg^{-1} soil) soil receiving 60 mg N kg^{-1} as urea which reduced to 14.3 mg kg^{-1} soil when same level of N (i.e. 60 mg kg^{-1} N as urea) was applied in the absence of calcium carbide. At half recommended N level (i.e. 30 mg kg^{-1}), NH_4-N contents were also reduced from 22.3 mg kg^{-1} soil to 10.11 mg kg^{-1} soil in the absence of CaC_2. Minimum NH_4-N concentration was observed in control receiving no CaC_2 and urea. Conversely NO_3-N concentration decreased from 29.6 to 10.5 mg kg^{-1} in soil amended with 30 mg CaC_2 kg^{-1} plus full recommended dose of N as compared to N alone, indicating the extent of nitrification in the absence of CaC_2. At half recommended N level, NO_3-N concentration decreased from 16.94 to 6.00 mg kg^{-1} in soil amended with 30 mg CaC_2 kg^{-1} plus half of the recommended dose of N as compare to half of the recommended dose of N alone. As far as oxidation of NH_4 is concerned, it was reduced and consequently estimated concentration of NH_4-N was 186 and 120 % higher with addition of 30 mg kg^{-1} CaC_2 with full and half dose of N over alone N levels, respectively. Similarly, NO_3-N concentration was 159 and 171 % greater in the treatments with full and half doses of N alone as compared to the same levels with addition of 30 mg kg^{-1} soil of calcium carbide, respectively.

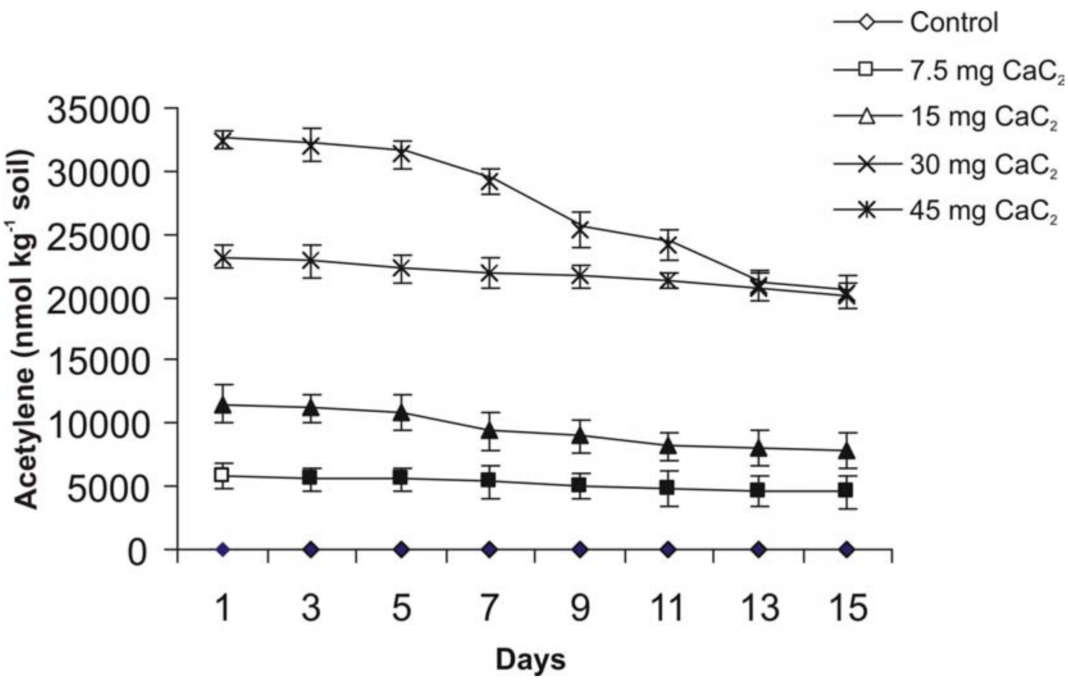

Figure 1. Acetylene production from calcium carbide amended soil as monitored for 15 days under laboratory conditions.

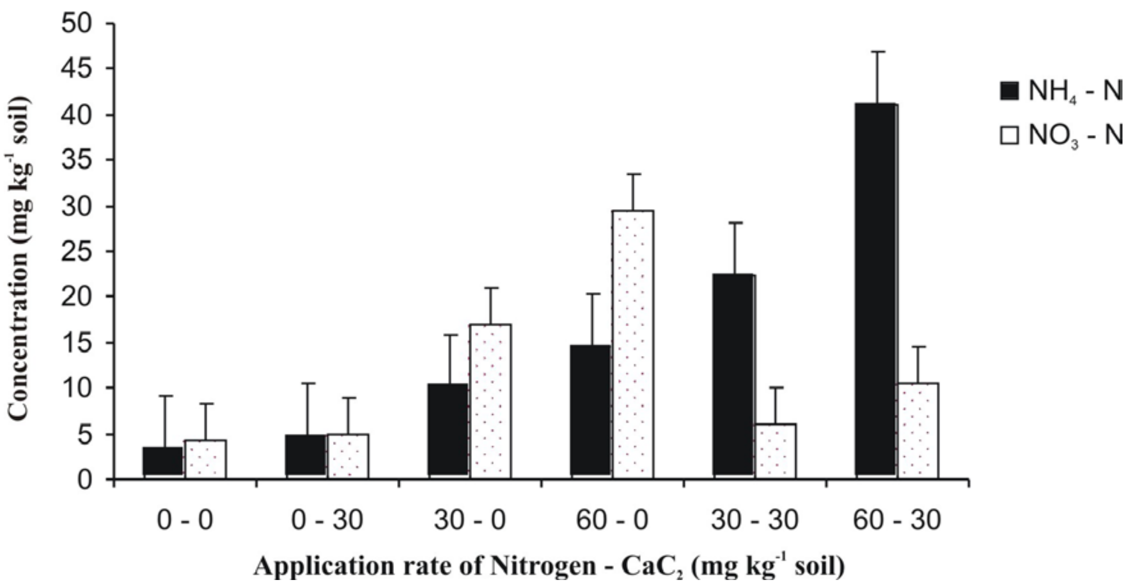

Figure 2. NH_4-N and NO_3-N contents of soil after CaC_2 application under laboratory conditions

Data regarding effect of calcium carbide application on okra green pod yield (Figure 3) indicated that application of calcium carbide in combination with N fertilizer increased the green pod yield. Maximum green pod yield (532 g pot^{-1}) was observed in treatment receiving N-CaC_2 of 30-30 mg kg^{-1} soil whereas minimum yield (201 g pot^{-1}) was observed in control receiving no N and calcium carbide. It was also observed that N application at the rate of 60 mg kg^{-1} with 30 mg kg^{-1} calcium carbide decreased green pod yield due to morphological disorders in plants.

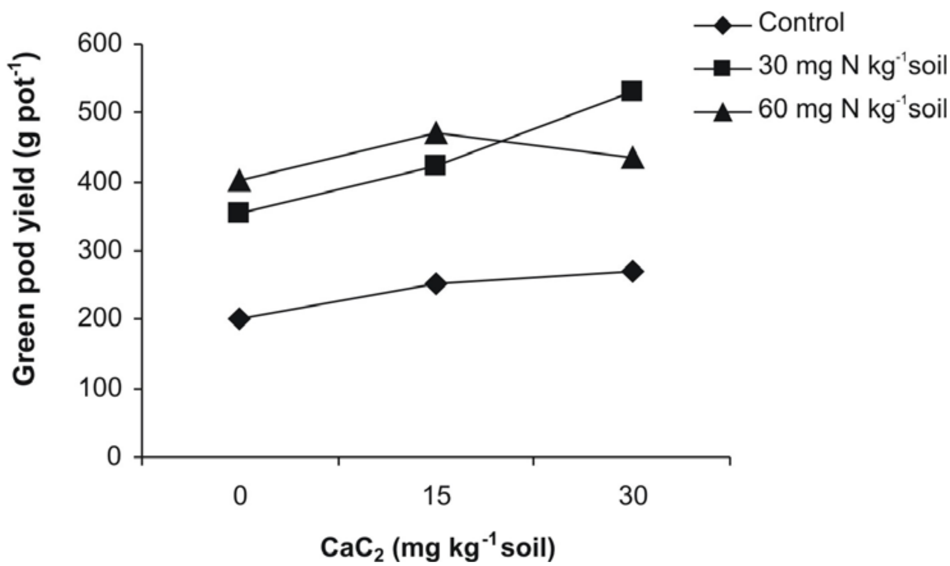

Figure 3. Effect of CaC_2 application on green pod yield of okra.

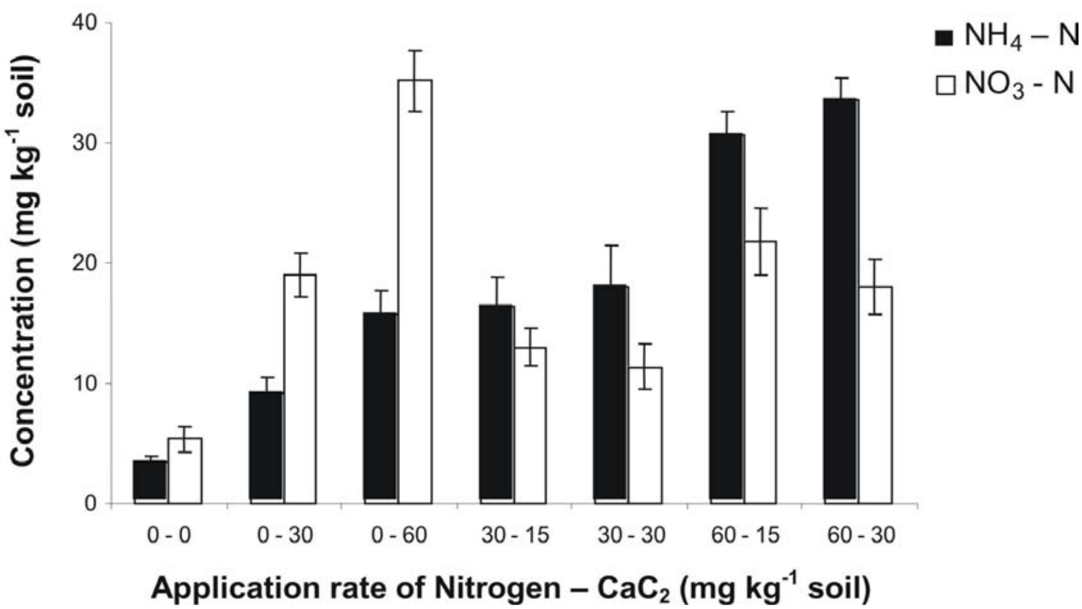

Figure 4. Ammonium and nitrate contents in okra grown pots 10 weeks after the application of calcium carbide.

NH_4-N and NO_3-N contents in okra grown pots 10 weeks after the application of calcium carbide clearly showed the effect of calcium carbide on type of nitrogen ion in the soil. There was increase in NH_4-N contents whereas decrease in NO_3-N as shown in Figure 4 by the application of CaC_2 in okra grown pot conditions, indicating the inhibitory effect of calcium carbide on nitrification.

Discussion

The application of encapsulated CaC_2 significantly suppressed the oxidation of NH_4^+-N to NO_3-N in a soil-amended with N fertilizer (urea). This suggests that CaC_2 could be used as a nitrification inhibitor. The observed suppressive effect of CaC_2 on NH_4-oxidation is also supported by the findings of other researchers (Sahrawat, 1989; Porter, 1992; Yaseen *et al*., 2006). The results also revealed that encapsulated CaC_2 plus N fertilizer enhanced NH_4-N contents in soil as compared to NO_3-N contents in soil and this situation persist up to six weeks as demonstrated in the study. The loss of N from applied fertilizer is of great concern not only because of economic reasons but also due to the pollution potential of different N forms. Some of the adverse effects of excessive N include methemoglobonemia in infants due to NO_3 and NO_2 in water and food, cancer due to secondary amines, respiratory illness due to NO_3, NO_2 and HNO_3 in aerosols, eutrophication due to N in surface waters, material and ecosystem damage due to HNO_3 in rain waters and depletion of stratospheric ozone due to NO and N_2O (Azam and Farooq, 2003). It is because of these concerns that concerted efforts have been made to reduce the N losses from N fertilizers by increasing the fertilizer use efficiency of crops. Therefore, CaC_2 can be used as an effective nitrification and denitrification inhibitor improving the N fertilizer use efficiency by keeping it in NH_4-N form for a longer period of time. Similar results from CaC_2 application were also observed by Bronson and Mosier (1991), Freney *et al*. (1993), Thompson (1996), Aulakh *et al*. (2001), Pathak and Nedwell (2001) and Melissa and Ross (2005). Nitrification inhibitors have indeed been reported to improve crop yields not only by maintaining higher levels of NH_4^+ but by decreasing the losses of N through denitrification and NO_3^- leaching as well. In addition, CaC_2 may also serve as a supplemental source of Ca which is useful for plant growth.

Acknowledgements

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Table 1. Physico-chemical characteristics of soil used in experiments.

Characteristics	Units	Value
Sand	%	49.68
Silt	%	28.74
Clay	%	21.58
Texture class	**Sandy clay loam**	
Saturation percentage	%	31.0
pH_s		7.83
EC_e	$dS\ m^{-1}$	2.51
CEC	$cmol_c\ kg^{-1}$	4.38
Organic matter	%	0.61
Total Nitrogen	%	0.031
Available Phosphorus (P)	$mg\ kg^{-1}$ soil	6.53
Extractable Potassium (K)	$mg\ kg^{-1}$ soil	173

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