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Response of Vegetables to NPK Briquette Deep Placement

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ABSTRACT

The performance was evaluated during April to November, 2012 of the deep placement of NPK fertilizer briquettes compared with broadcast incorporation of N, P, and K, with each treatment supplying S, Zn and B fertilizers as a blanket dose, for vegetables like cucumber, taro and bitter gourd. The experiments were conducted under on-station and on-farm conditions in three locations in Bangladesh: at Jessore for cucumber, at Patuakhali for bitter gourd and for taro at Mymensingh (only on-farm) and at Jessore (only on-station). Six treatments were designed to evaluate the crop responses to: the broadcast incorporation of N, P, and K applied as prilled urea (PU), triple super phosphate (TSP), and muriate of potash (MOP); deep placement of urea briquettes and NPK briquettes; native fertility; and general farmer practice. The size of the NPK briquettes and the urea briquettes was 3.4 g and 1.8 g, respectively. The results showed that deep placement of the NPK briquettes gave higher vegetable yields (28.8% for cucumber, 25.6% for taro and 10.8% for bitter gourd) and higher gross margins over broadcast incorporation of N, P, and K. The amount of NPK nutrient uptake and recovery by all three vegetable crops was also higher in the NPK briquette treatment compared to the broadcast treatment with PU, TSP and MOP.

Keywords: vegetables, NPK briquette, fertilizer deep placement

INTRODUCTION

Deep placement of urea in wetland rice fields has been widely recognized as an effective management practice for transplanted rice (Savant and Stangel, 1990; Misra *et al*., 1995; Bowen *et al*., 2005). Fertilizer briquettes have been tested and their use slowly adopted in rice paddies in countries such as Bangladesh, Vietnam and the Philippines (Bautista *et al*., 2001) through an initiative of the International Fertilizer Development Centre in Bangladesh.

In Bangladesh, there has been a sharp increase in the demand for and cultivation of vegetable crops for domestic and export markets in recent years, but poor soil fertility is the major constraint for vegetable production (Moslehuddin *et al.,* 1997). Such growth in the vegetable industry has placed significant pressure on the country's natural resources; particularly as over 80% of

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the country's population is dependent upon the land for income and to fulfill their basic needs (Rahman and Manprasert, 2006). In many parts of the country where access to irrigation water exists, crop rotations have been intensified to three crops per year to meet the rising food demand and to gain additional cash income; however, declining soil fertility is an important concern for agriculture in Bangladesh (Hossain and Kashem, 1997; Rahman and Thapa, 1999). Vegetable crops are very responsive to soil fertility status (Moslehuddin *et al*., 1997), so nutrient management strategies should be used on vegetable farms to maximize the benefits of fertilizer application on crop yields and fruit quality while minimizing nutrient loss to the environment. Fertilizer briquettes hammered into the ground reduce runoff, fixation, leaching, and volatilization loss (Bautista *et al*., 2001). Now-a-days urea briquettes are a popular nitrogenous fertilizer for wetland rice in Bangladesh and they have been found to be quite superior to prilled urea (PU) in terms of N efficiency (Bhuiyan and Shah, 1990; Mishra *et al*., 1999). Application of urea briquettes has proved to be profitable in different upland crops such as brinjal, tomato, cabbage, cauliflower, potato, maize and banana and the results to date have shown that 10–20% urea could be saved and the yield increased substantially by the use of urea briquettes instead of prilled urea (Hossain *et al.,* 2003). The rapid rise in fertilizer prices coupled with the low nutrient recovery in vegetable crop production (Keeney and Kemp, 2002) and associated environmental problems have prompted research to re-examine crop nutrient management practices, especially on vegetable crops where reasonable yield and quality are expected from fertilizer application. The objective of this study in Bangladesh was to evaluate the effect of fertilizer deep placement on the yield and nutrient uptake of a number of vegetable crops during April to November 2012.

MATERIALS AND METHODS

Location and soil sampling

Field experiments were carried out on-station as well as on-farm to evaluate the effectiveness of the deep placement of NPK briquettes on cucumber, bitter gourd and taro. The research was carried out during April to November, 2012 at Jessore, Bangladesh (located in agro-ecological zone-11; AEZ-11) for cucumber and taro (on-station), at Mymensingh (AEZ-9) for taro (on-farm) and at Patuakhali (AEZ-13) for bitter gourd. The physico-chemical properties of cow dung at the different study sites are presented in Table 1. The chemical properties of soil samples at the different study sites before planting were analyzed and the results are presented in Table 2.

Plant selection and plant analysis

Details of crop variety, plot size, spacing and the dates of planting and harvest are presented in Table 3. The total economic and biological yields were determined at harvest. Biomass samples were collected at harvest and analyzed for the N, P and K contents. The apparent nutrient recovery percentage was calculated as shown by Hashemidezfooli *et al*. (1998).

Table 1 Physico-chemical properties of cow dung at different study sites in Bangladesh.

Location	Color	Type	Odor	Moisture content (%)	pH	OM (%)	Total N (%)	P (%)	K (%)	S (%)
Jessore	Ash-gray	Non-granular	Mild	12.5	7.2	12.4	1.1	1.2	0.8	0.34
Patuakhali	Ash-gray	Non-granular	Mild	12.4	7.1	12.2	1.2	1.1	0.9	0.31
Mymensingh	Ash-gray	Non-granular	Mild	12.2	6.9	11.9	1.0	0.9	0.7	0.30

OM = Organic matter.

Experimental design and fertilizer management

NPK (prilled urea (PU) for N, di-ammonium phosphate (DAP) for N and P, and muriate of potash (MOP) for K) briquettes, urea briquettes and straight fertilizer (prilled urea, triple super phosphate (TSP) for P, MOP, gypsum for S, zinc sulphate monohydrate for Zn and Boric acid for B) were used to provide different nutrient combinations. Commercial briquette-producing machines modify the physical characteristics of conventional urea fertilizer as the process compresses the multiple urea particles to achieve a granule that is about 15 to 20 times larger than conventional PU (Savant and Stangle, 1990). Six treatments were designed to evaluate the crop response to the broadcast incorporation of N, P and K, deep placement of urea briquettes and NPK briquettes, and of common farmer practice. The treatments were selected on the basis of soil-test based fertilizer application recommended following Bangladesh Agricultural Research Council (2005) except for the treatment involving common farmer practice. Crop-wise, the six different treatments (Table 4) were tested using a randomized complete block design with three replications. Briefly, these treatments were: T_1, PU + other fertilizers + cowdung; T_2, 10% less urea briquette + other fertilizers + cowdung; T_3, 10%

Table 2 Chemical properties of soil samples at different study sites before planting.

Location	pH	OM (%)	Ca	Mg	K	Total N (%)	P	S	B	Zn
			Meq per 100g soil				μg per g soil			
Cucumber (on-farm)	7.4	1.53	6.0	2.0	0.16	0.090	15	14	0.30	2.00
Cucumber (on-station)	7.4	1.53	6.4	2.0	0.16	0.085	16	15	0.30	1.50
Bitter gourd (on-farm)	7.8	1.10	10.0	7.7	0.16	0.082	15	25	0.20	1.70
Bitter gourd (on-station)	7.6	1.20	9.0	6.0	0.18	0.080	17	28	0.20	1.80
Taro (on-farm)	5.4	1.51	6.0	3.0	0.16	0.080	13	14	0.22	1.70
Taro (on-station)	7.5	1.25	6.5	2.5	0.16	0.060	17	16	0.20	1.72
Critical level	-	-	2.0	0.5	0.12	-	10	10	0.20	0.60

OM = Organic matter; Meq = Milliequivalents.

Table 3 Experimental sites in Bangladesh and plant information.

Location	Crop	Variety	Plot size (m^2)	Spacing (cm × cm)	Planting date	Date of harvest	
						Begin	End
On-station, Jessore	Cucumber	Alrounder	8 × 5	100 × 100	Apr 22, 2012	Jun 10, 2012	Jul 15, 2012
On-farm, Jessore	Cucumber	Alrounder	8 × 5	100 × 100	Apr 18, 2012	Jun 06, 2012	Jun 30, 2012
On-station, Patuakhali	Bitter gourd	Hybrid (Tia)	8 × 5	100 × 100	Apr 30, 2012	Jun 25, 2012	Jul 07, 2012
On-farm, Patuakhali	Bitter gourd	Hybrid (Tia)	8 × 5	100 × 100	Apr 21, 2012	Jun 21, 2012	Jul 26, 2012
On-station, Jessore	Taro	Latiraj	7.8 × 4.5	60 × 45	May 04, 2012	Jul 04, 2012	Sep 11, 2012
On-farm, Mymensingh	Taro	BARI Panikachu 2	7.8 × 4.5	60 × 45	Apr 16, 2012	Jul 10, 2012	Nov 12, 2012

Table 4 Treatment details for all crops.

Cucumber (on station and on farm)
T_1- PU (N 70 kg.ha^{-1}) + other fertilizers (P, K, S, Zn, B at 20, 35, 16, 2.5, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_2- 10% less urea briquette (N 63kg. ha^{-1}) + other fertilizers (P, K, S, Zn, B at 20, 35,16, 2.5, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_3- 10% less NPK briquette (N 63 kg. ha^{-1}) + other fertilizers (P, K, S, Zn, B at 18, 31.5, 16, 2.5, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_4- Farmer practice (N, P, K, S, Zn, B at 75, 24, 25, 20, 2, 1 kg. ha^{-1}, respectively, and cowdung 3 t.ha^{-1})
T_5- Native fertility
T_6- Same as T_3 without cowdung
Bitter gourd (on station and on farm)
T_1- PU (N 80 kg. ha^{-1})+ other fertilizers (P, K, S, Zn, B at 30, 35, 8, 2.5, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_2-10% less urea briquette (N 72 kg.ha^{-1}) + other fertilizers (P, K, S, Zn, B at 30, 35, 8, 2.5, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_3- 10% less NPK briquette (N 72 kg.ha^{-1}) + other fertilizers (P, K, S, Zn, B at 27, 31.5, 8, 2.5, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_4- Farmer practice (N, P, K, S, Zn, B at 58, 20, 25, 9, 2.7, 1.28 kg.ha^{-1} and cowdung 3 t.ha^{-1})
T_5- Native fertility
T_6- Same as T_3 without cowdung
Taro (on station)
T_1-PU (N 135 kg ha^{-1}) + other fertilizers (P, K, S, Zn, B at 10, 60, 15, 2, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_2-10% less urea briquette (N 121.5 kg.ha^{-1})+ other fertilizers (P, K, S, Zn, B at 10, 60, 15, 2, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_3- 10% less NPK briquette (N 121.5 kg.ha^{-1})+ other fertilizers (P, K, S, Zn, B at 9, 54, 15, 2, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_4- Farmer practice (N, P, K, S, Zn, B at 120, 15, 50, 10, 3, 1 kg.ha^{-1}, respectively, and cowdung 2 t.ha^{-1})
T_5- Native fertility
T_6- Same as T_3 without cowdung
Taro (on farm)
T_1- PU (N 90 kg.ha^{-1})+ other fertilizers (P, K, S, Zn, B at 20, 60, 15, 2, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_2- 10% less urea (N 81 kg.ha^{-1}) + other fertilizers (P, K, S, Zn, B at 20, 60, 15, 2, 1.5 kg.ha^{-1}, respectively, $N_{81}P_{20}K_{60}$ $S_{15}Zn_2B_{1.5}$ kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_3- 10% less N (N 81 kg ha^{-1})+ other fertilizers (P, K, S, Zn, B at 18, 54, 15, 2, 1.5 kg.ha^{-1}, respectively, and cowdung 4 t.ha^{-1})
T_4- Farmer practice (N, P, K, S, Zn, B at 115, 25, 40, 0, 0, 0, t.ha^{-1}, respectively, and cowdung 5 t.ha^{-1})
T_5- Native fertility
T_6- Same as T_3 without cowdung

PU = Prilled urea.

less NPK briquette + other fertilizers + cowdung; T_4, farmer practice; T_5, native fertility; and T_6, the same as T_3 without cowdung.

Fertilizer application

Cucumber: At the time of final plowing, the full amounts of well decomposed cow dung (as organic matter source) and S, Zn and B fertilizers were applied and mixed with the soil thoroughly. Fertilizers containing phosphorus and potash were applied basally except in the T_3 and T_6 treatments. Ten days after transplanting seven NPK briquettes (for T_3 and T_6) and eight urea briquettes (for T_2) per plant were applied in a ring around the stem—the urea and the NPK briquettes were applied 9–10 cm apart from the base of the plant and 7–8 cm deep into the soil. Subsequently, the fertilizers were completely covered by soil. In treatment T_1, one half of the N was basally incorporated and the remaining N was applied at 30 d after transplanting.

Bitter gourd: At the time of final plowing, the full amounts of well decomposed cow dung (as organic matter source) and S, Zn and B fertilizers were applied and mixed with the soil thoroughly. Fertilizers containing phosphorus and potash were applied basally except in the T_3 and T_6 treatments. Ten days after transplanting nine NPK briquettes (for T_3 and T_6) and 10 urea briquettes (for T_2) for each plant were applied using the ring method. The N and NPK briquettes were applied 9–10 cm apart from the base of the plant and 7–8 cm deep. Subsequently, the fertilizers were covered completely with soil. In treatment T_1, N was applied in two equal installments at 10 and 28 d after transplanting.

Taro: At the time of final plowing, the full amounts of well decomposed cow dung (as organic matter source) and S, Zn and B fertilizers were applied and mixed with soil thoroughly. Fertilizers containing phosphorus and potash were applied basally except in the T_3 and T_6 treatments. In the on-farm treatments (Trishal and Mymensingh), 12 d after transplanting, five NPK briquettes (for T_3 and T_6) and five urea briquettes (for T_2) for each plant were applied whereas in Jessore, 12 d after transplanting, five NPK briquettes (for T_3 and T_6) and seven urea briquettes (for T_2) for each plant were applied using the ring method. The urea and NPK briquettes were applied 9–10 cm apart from the base of the plant and 7–8 cm deep. Subsequently, the fertilizers were well covered with soil. In treatment T_1, N was applied in two equal installments at 30 and 60 d after planting.

Briquette production

Briquettes of different sizes were prepared to provide the different nutrient combinations and rates (Table 5).

Data analysis

The yield and the N, P and K uptake data were processed and analyzed. Mean comparisons were performed using the least significant difference (at the $P < 0.05$ level).

Table 5 Nutrient ratios and briquettes numbers for different crops.

Crops	NPK ratio for briquettes	NPK briquette weight (g)	Urea briquette weight (g)	Number of NPK briquettes per plant (T_3,T_6)	Number of urea briquettes per plant (T_2)
Bitter gourd	7.2:2.7:3.15	3.4	1.8	9	9
Aroid (Mymensingh)	8.1:1.8:5.4	3.4	1.8	5	5
Aroid (Jessore)	12.15:0.9:5.4	3.4	1.8	5	7
Cucumber	6.3:1.8:3.15	3.4	1.8	7	8

T_2, T_3, T_6 = See Table 4 for details of treatments.

RESULTS AND DISCUSSION

A significantly higher fresh marketable yield of cucumber was recorded with the use of 10% less NPK briquettes (T_3) compared to the prilled urea (T_1) and urea briquettes (T_2) (Table 6). The increased fruit yield in cucumber was 28.8% with the NPK briquettes and 21.9% with the urea briquettes when compared with PU (T_1). With taro, (averaged for the two locations), significantly higher rhizome (20.65 t.ha^{-1}) and stolon (31.4 t. ha^{-1}) yields were obtained from the NPK briquettes, representing 20.1 and 25.55% higher yields, respectively, compared to PU. On the other hand, the urea briquettes (T_2) produced 12.8 and 14.3% higher rhizome and stolon yields relative to PU (prilled urea).

It was observed that the deep placement of NPK briquettes (T_3) was significant in producing the highest yields of bitter gourd (42.0 t.ha^{-1}) followed by urea briquettes (39.5 t.ha^{-1}) which were 10.8 and 4.2% higher than for PU (T_1), respectively (Table 6). The treatment-wise cost and return analysis of all crops is presented in Table 6. The highest gross margin was obtained with the NPK briquette treatment at USD 4,217 ha^{-1}, USD 4,461 ha^{-1} and USD 3,635 ha^{-1}, for cucumber, taro and bitter gourd, respectively (Table 7).

It was observed that the application of nutrients like N and NPK was reduced (10% each in the T_2 and T_3 treatments, respectively) compared to prilled urea (T_1) in all the tested crops (Table 8). Although the amount of N saved was equal in the T_2 and T_3 treatments, some P and K was also saved in the T_3 treatment. As a result, the financial benefits were greater for the T_3 treatment than for T_2. It was observed that the saved amounts of N and K were higher for taro than for cucumber and bitter gourd. However, the saved amount of P was higher for bitter gourd than for the other crops. As a whole, the financial benefits from the fertilizer nutrient savings were higher with taro than with the other two crops.

Based on the treatment comparisons of the urea and NPK briquettes with PU (T_1), the benefits to the vegetable crops can largely be attributed to the deep placement of the NPK and urea briquettes. The combined NPK briquette deep placement in a single operation provided all the N, P, and K needs for the crop compared with the conventional practice. In addition, environmental losses from fertilizers were practically reduced. The NPK briquettes can also be modified to match soil supply and crop requirements for site-specific nutrient management. Kapoor *et al*. (2008) reported that significantly higher grain and straw yield of rice was observed with deep placement of NPK briquettes compared to the broadcast application of NPK. Work on cabbage by Firake *et al*. (2004) suggested that the placement of NPK briquettes at 10 cm depth in the soil maintained a high level of NH_4-N during the active absorption period by the cabbage crop. In the current study, deep placement of fertilizer briquettes resulted in higher vegetable yields compared to conventional fertilizer practice. These results were consistent with the yield increases reported by Kadam and Sahane (2001) for tomato (26%), by Bhattarai *et al*. (2011) for cucumber (22%) and yard long bean (9%) using fertilizer briquette deep placement compared to conventional fertilizer practice. Khalil *et al*. (2009) reported that the volatilization loss of PU is very high and farmers lose a huge amount of money on N fertilizer and these authors proposed that to control this loss, deep placement of fertilizer may be a good option to minimize production costs as well as to increase yield.

The amount of combined (both on-station and on-farm) N, P and K uptake by cucumber, taro and bitter gourd are presented in Table 9. The total N, P, and K uptakes were significantly higher due to the deep placement of the NPK briquettes, although 10% less NPK fertilizer was applied compared to the PU treatment. The total N and K uptake with the deep placement of the NPK briquettes was significantly higher than for the broadcast application for all crops. The P uptake was also significantly higher for cucumber and taro

Table 6 On-station, on-farm and average yield response to fertilizer application by deep placement versus conventional broadcast application.

Cucumber

Location	Treatment	Yield ($t.ha^{-1}$) on-station	Yield ($t.ha^{-1}$) on-farm	Average ($t.ha^{-1}$)	Percentage yield increase over T_1
Jessore	T_1 PU + OF	16.2	16.1	16.15	-
	T_2 Urea briquettes + OF	20.8	18.6	19.7	21.9
	T_3 NPK briquettes + OF	21.9	19.8	20.8	28.8
	T_4 Farmer practice	16.5	16.8	16.6	2.8
	T_5 Control	13.4	14.5	14	-13.3
	T_6 NPK briquette -no cowdung + OF	18.7	17.4	18	11.4
	Least significant difference (0.05)	1.16	1.09	1.1	
	Coefficient of variation (%)	6.7	7.9	7.2	

Taro

Location	Treatment	Rhizome yield ($t.ha^{-1}$)	Percentage yield increase over T_1	Stolon yield ($t.ha^{-1}$)	Percentage yield increase over T_1
Mymensingh (On-farm)	T_1 PU + OF	17.6	-	36.2	-
	T_2 Urea briquette + OF	20.7	17.6	39.7	9.6
	T_3 NPK briquette + OF	22.1	25.6	41.5	14.6
	T_4 Farmer practice	16.3	-7.4	30.2	-16.5
	T_5 Control	11.9	-32.3	24.2	-33.1
	T_6 NPK briquette -no cowdung + OF	18.5	5.1	38.6	6.6
	Least significant difference (0.05)	1.01		1.54	
	Coefficient of variation (%)	10.0		6.1	

Taro

Location	Treatment	Rhizome yield ($t.ha^{-1}$)	Percentage yield increase over T_1	Stolon yield ($t.ha^{-1}$)	percent yield increased over T_1
Jessore (On station)	T_1 PU + OF	16.8	-	15.6	-
	T_2 Urea briquette + OF	18.1	7.7	19.5	25.0
	T_3 NPK briquette + OF	19.2	14.3	21.3	36.5
	T_4 Farmer practice	13.2	-21.4	14	-10.2
	T_5 Control	7.4	-55.9	7.1	-54.5
	T_6 NPK briquette -no cowdung + OF	17.6	4.7	18.9	21.2
	Least significant difference (0.05)	0.93		1.19	
	Coefficient of variation (%)	7.7		8.2	

Bitter gourd

Location	Treatment	Yield ($t.ha^{-1}$) on-station	Yield ($t.ha^{-1}$) on-farm	Average ($t.ha^{-1}$)	percent yield increased over T_1
Patuakhali	T_1 PU + OF	36.0	39.8	37.9	-
	T_2 Urea briquette + OF	36.5	42.5	39.5	4.2
	T_3 NPK briquette + OF	38.6	45.5	42	10.8
	T_4 Farmer practice	35.8	32.8	34.3	-9.4
	T_5 Control	27.3	24.9	26.1	-31.1
	T_6 NPK briquette -no cowdung + OF	36.3	39.9	38	0.3
	Least significant difference (0.05)	5.4	1.54	3.4	
	Coefficient of variation (%)	6.0	4.6	5.3	

PU = Prilled urea; T_1–T_6 = See Table 4 for details of treatments; OF = Other fertilizers as given in Table 2.

with the NPK briquettes. Based on the treatment comparisons, the benefits to the vegetables crops can largely be attributed to the deep placement of the NPK briquettes. Kapoor *et al*. (2008) and Islam *et al*. (2011) observed significantly higher N, P, and K uptakes with deep placement of NPK briquettes compared to a broadcast application.

In general, the highest N, P and K recoveries were obtained with the deep placement of NPK briquettes for all crops (Table 10). The

Table 7 Cost and return analysis of cucumber, taro and bitter gourd affected by fertilizer application with deep placement versus conventional broadcast application.

Treatment		Gross return ($USD.ha^{-1}$)	Total variable cost ($USD.ha^{-1}$)	Gross margin ($USD.ha^{-1}$)
Cucumber				
T_1	PU + OF	5047	2130	2917
T_2	Urea briquettes + OF	6156	2288	3868
T_3	NPK briquettes + OF	6500	2283	4217
T_4	Farmer practice	5188	2276	2912
T_5	Control	4375	2117	2258
T_6	NPK briquettes -no cowdung + OF	5625	2258	3367
Taro				
T_1	PU + OF	5286	1945	3341
T_2	Urea briquettes + OF	6035	1945	4090
T_3	NPK briquettes + OF	6404	1943	4461
T_4	Farmer practice	4513	1902	2611
T_5	Control	3176	1732	1444
T_6	NPK briquettes -no cowdung	5842	1908	3934
Bitter gourd				
T_1	PU + OF	5685	2666	3019
T_2	Urea briquettes + OF	5925	2668	3257
T_3	NPK briquettes + OF	6300	2665	3635
T_4	Farmer practice	5145	2591	2554
T_5	Control	3940	2466	1474
T_6	NPK briquettes -no cowdung + OF	5700	2630	3070

T_1–T_6 = See Table 4 for details of treatments; PU = Prilled urea; OF = other fertilizers as given in Table 2.

Table 8 Nutrient savings and financial benefits for fertilizer deep placement over prilled urea (T_1).

Treatment		Nutrient saving ($kg.ha^{-1}$)			Financial benefits ($USD.ha^{-1}$)
		N	P	K	
Cucumber					
T_2	Urea briquettes	7	0	0	3.80
T_3	NPK briquettes	7	2	3.5	7.86
Taro					
T_2	Urea briquettes	11.3	0	0	6.13
T_3	NPK briquettes	11.3	1.5	6	10.44
Bitter gourd					
T_2	Urea briquettes	8	0	0	4.35
T_3	NPK briquettes	8	3	3.5	9.79

T_1–T_3 = See Table 4 for details of treatments.

N recovery levels were greater than 70% with the NPK briquettes for all crops. The synergistic effect of the N efficiency also improved the P and K efficiencies. The greater recovery of P and K with the NPK briquettes compared to the urea briquettes indicated that the improvement in P and K efficiency was also due to the deep placement of the NPK.

The positive impact of cowdung was evident from the higher yield, gross margin, nutrient uptake and nutrient recovery when comparing the NPK briquettes with cowdung (T_3) and without cowdung (T_6). This indicated that the integrated management of manure with the deep placement in upland crops can play an important role in increasing the productivity and in improving nutrient use efficiency. However, PU, even when combined with cowdung (T_1) had a lower overall yield, gross margin, uptake and recovery than for the NPK briquettes without cowdung (T_6).

Table 9 N, P and K uptake (combined) by cucumber, taro and bitter gourd as affected by fertilizer application with deep placement versus conventional broadcast application.

Treatment		Total Nutrient uptake (kg.ha^{-1})								
		Cucumber			Bitter gourd			Taro		
		N	P	K	N	P	K	N	P	K
T_1	PU + OF	97	30	122	130	24	123	119	18	146
T_2	Urea briquettes + OF	102	34	132	142	25	132	133	19	167
T_3	NPK briquettes + OF	108	37	143	149	26	141	145	21	160
T_4	Farmer practice	85	29	115	116	20	113	105	16	123
T_5	Control	59	25	96	96	19	99	69	8	67
T_6	NPK briquettes - no cowdung + OF	99	35	127	125	21	122	131	19	156
Least significant difference (0.05)		4.44	2.84	5.64	5.47	4.65	3.87	5.01	2.52	4.96
Coefficient of variation (%)		6.5	11.4	5.0	4.6	14.4	4.2	3.9	12.2	5.6

T_1–T_6 = See Table 4 for details of treatments; PU = Prilled urea; OF = Other fertilizers as given in Table 2.

Table 10 Apparent N, P and K recovery by cucumber, taro and bitter gourd as affected by fertilizer application with deep placement vs. conventional broadcast application.

Treatment		Apparent nutrient recovery (%)								
		Cucumber			Bitter gourd			Taro		
		N	P	K	N	P	K	N	P	K
T_1	PU + OF	54.3	25.0	74.3	42.5	16.7	68.6	44.4	66.7	131.7
T_2	Urea briquette+ OF	68.3	45.0	102.9	63.9	20.0	94.3	63.2	73.3	166.7
T_3	NPK briquette + OF	77.8	66.7	149.2	73.6	25.9	133.3	75.1	96.3	172.2
T_4	Farmer Practice	34.7	16.7	76.0	34.1	5.0	56.0	30.6	40.0	124.4
T_5	Control*	na	na	na	Na	na	Na	na	na	na
T_6	NPK briquette – no cowdung + OF	63.5	55.6	98.4	40.3	7.4	73.0	61.2	81.5	164.8

T_1–T_6 = See Table 4 for details of treatments; PU = Prilled urea; OF = Other fertilizers as given in Table 2.
na- Not applicable.

CONCLUSION

The deep placement of urea briquettes and NPK briquettes resulted in greater vegetable yields and in a generally higher uptake of nutrients compared with the broadcast application of NPK. The results also revealed that the yield increased by 14.6–36.5% while the input quantity of NPK fertilizers decreased by 10% and the gross margin also increased when the NPK fertilizer briquettes were used as the source of plant nutrients compared to when N, P and K were broadcast applied. Greater benefits were accrued with the integrated use of manures and the deep placement of briquettes. The deep placement of the NPK briquettes was largely beneficial to cucurbits like cucumber and bitter gourd and to tuber crops like taro. It is worthwhile recommending the deep placement of NPK instead of prilled urea and urea briquettes because with a single operation all the required N, P and K could be provided to crops.

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