IMPACT OF NUTRIENT MANAGEMENT, PLANTING DATE, AND LOCATION ON PAPAYA YIELD AND QUALITY IN BANGLADESH

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Papaya *(Carica papaya*) cultivation is currently widespread throughout Bangladesh. The average fruit yield is extremely low (i.e., 6.6 t ha^{-1}) and is most likely the result of plant disease (e.g., papaya ringspot virus), flooding, lack of varieties, and poor nutrient management. Over a two and one-half year period, eight field experiments were conducted at two different locations (i.e., Rangpur and Pabna area) in Bangladesh. In Rangpur, the objective of these experiments was to evaluate the effect of lime, poultry manure, and planting date on plant nutrition, soil fertility, and papaya production and availability. In the Pabna area, the objective of these experiments was to determine the effect of poultry manure, Zn, and B on plant nutrition, soil fertility, and papaya yield. In addition, the vitamin content of ripe papaya from both locations was determined. The experimental design for each of the experiments was a randomized complete block design with four replications. In Rangpur, the application of poultry manure substantially increased papaya yield. Manure application also generally increased the soil concentration of P, Ca, Mg, and Zn and the petiole concentration of P, Ca, Mg, and K. In contrast, the application of poultry manure lowered the soil concentration of Al and the petiole concentration of Mn and Zn. The application of lime had a very limited effect on yield, plant nutrition, and soil properties. In Rangpur, papaya that was transplanted in the fall provided ripe fruit approximately four to eight weeks earlier than papaya transplanted in the spring. In the Pabna area, even though the application of poultry manure tended to improve the soil fertility at this location, the application of poultry

manure, Zn, and/or B had a very limited effect on crop yield. Overall, there was very little difference in vitamin content among the treatments for either location, however, the papaya fruit from Rangpur tended to have higher vitamin content as compared to fruit from Pabna. In conclusion, the results from this study suggest that a combination of nutrient management and planting date has the potential to improve the production and availability of papaya in Bangladesh.

BIOGRAPHICAL SKETCH

Jacqueline King was born in Miami, Florida. As an undergraduate, she attended the University of Florida and received her B.S. in Entomology and Nematology. During her studies, she was employed as a field research assistant for an entomologist and later for a nematologist in Gainesville, Florida. Afterwards, she obtained an M.S. from the University of Florida in Agronomy. She is currently pursing her Ph.D. in the Crop and Soil Sciences department at Cornell University. As part of her Ph.D. research, she lived in Bangladesh for over two and one-half years.

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CHAPTER ONE

GENERAL INTRODUCTION

Papaya (*Carica papaya*), of the family Caricaceae, is a large herbaceous plant that is currently cultivated throughout the tropics and subtropics. It is most commonly grown between 23^o north and south latitude, however, at low elevations, it can be cultivated between 32 ^{o} north and south latitude (Nakasone and Paull, 1998; Chan, 1983). Papaya, whose common names include papaw or pawpaw, is believed to have originated from Mexico and Central America (Chan, 1983). Beginning in the mid-1500s, the Spaniards and the Portuguese collected papaya seed from Central and South America and distributed it to their colonies in Africa, South and Southeast Asia, and the Pacific (Manshardt, 1992; Morton, 1987).

Papaya grows best at temperatures between 21 and 33^{o}C with at least 100 mm of rainfall or irrigation per month. It can be cultivated on a wide range of soils, but prefers soils with good drainage and a pH between 5.0 and 7.0 (Nakasone and Paull, 1998; Nishina et al., 2000). Papaya is very sensitive to excessive soil moisture and flooded conditions will usually result in plant death (Malo and Campbell, 1994). In addition, papaya plants can also be damaged by frost and high winds (Malo and Campbell, 1994).

Papaya has a single stem with large palmately shaped leaves (Nakasone and Paull, 1998). It is a polygamous species that is able to produce plants with three types of flowers: male (staminate), female (pistillate), and hermaphrodite (Morton, 1987). Papaya has the potential to grow to 9 meters in height and fruit size can range from 0.25 kg to 6.8 kg (Nakasone and Paull, 1998). Depending upon the environment and location, papaya can supply ripe fruit within nine to twelve months after sowing (Gonsalves, 1998). When ripe, the color of the fruit can range from a pale yellow to a deep red and can be round, pear-shaped, or oblong (Nakasone and Paull, 1998).

Papaya cultivation is currently widespread throughout Bangladesh. Out of all the countries worldwide that produce papaya, Bangladesh ranks 12th in the amount of area harvested with approximately 7690 ha under papaya cultivation (FAOSTAT, 2005). However, Bangladesh ranks 50th in the average yield among papaya producing countries with a yield of only 6.6 t ha^{-1} (FAOSTAT, 2005). In comparison, the average yield of papaya cultivated in the U.S.A. (i.e., Hawaii) is 24.9 t ha^{-1} or roughly four times greater than the average yield found in Bangladesh (FAOSTAT, 2005). Overall, the major constraints to papaya production in Bangladesh include plant disease (e.g., papaya ringspot virus), lack of available varieties or cultivars, flooding, and nutrient management.

In Rangpur and Pabna, Bangladesh, 120 households (i.e., 60 respondents from each area) were randomly selected to participate in a survey on papaya production and consumption at the homestead level (J. King, unpublished data, 2005). Of those interviewed, 93% had papaya plants in their home gardens. For those households with papaya plants in their gardens, 27% had one to two papaya plants, 25% had three to four papaya plants, 21% had five to six papaya plants, and 27% had seven or more papaya plants. Overall, the majority of individuals surveyed (i.e., 73%) had less than seven papaya plants. The quantity of papaya plants for each household was comparable between Rangpur and Pabna. For example, 70% and 77% of households had less than seven plants for Rangpur and Pabna, respectively.

As opposed to planting papaya directly from seed, the majority of those interviewed (i.e., 82%) transplanted papaya seedlings that they had either collected or purchased from their neighbor, the local market, or a plant nursery. Most of the respondents (i.e., 87%) planted seedlings during February through April which is considered the traditional planting time in Bangladesh. In terms of fertilizer management, 24% of those interviewed did not apply any fertilizer to their papaya plants, 33% applied only organic fertilizer (e.g., poultry manure, cowdung, and household waste), 42% applied a combination of organic and inorganic fertilizer (e.g., urea, triple super phosphate), and 1% applied only inorganic fertilizer. Generally those households with seven or more papaya plants were more likely to apply inorganic or chemical fertilizer. Households with a fewer number of papaya plants were more likely to either not apply any fertilizer or apply only organic fertilizer. For example, of those interviewed with at least seven plants, approximately 80% applied a combination of organic and chemical fertilizer. In contrast, of those interviewed with fewer than seven plants, the majority (i.e., 70%) either did not apply any fertilizer or only applied organic fertilizer. In addition, 100% of those interviewed who did not apply any fertilizer had six plants or less in their home gardens. Overall, only 19% of respondents in Rangpur and Pabna applied micronutrient fertilizer (e.g., zinc, boron) to their papaya plants.

Papaya has the potential to produce fruit year-round and is either consumed ripe (e.g., as a dessert) or green (e.g., as a cooked vegetable or raw in a salad) (Manshardt, 1992). Respondents from the Rangpur and Pabna survey stated that papaya production was lower during December through May (J. King, unpublished data, 2005). This time period corresponds with the winter season and the planting of new papaya seedlings in Bangladesh. When asked if they harvested more green or ripe papaya from their homestead gardens, 7% replied that they harvested more green papaya, 18% replied that they harvested more ripe papaya, and the remaining respondents (i.e., 75%) replied that the harvested equal amounts of both. The results from the survey also showed that approximately 57% of respondents sold papaya from their garden. Those individuals who had seven or more plants were more likely to sell papaya from their homestead gardens. For example, roughly 75% of households with greater than six plants sold papaya from their gardens, while only approximately 50% of households with six plants or fewer sold papaya from their home gardens. When respondents in both locations were asked if they had a papaya plant that produced more fruit, would they consume or sell the additional papaya, the majority of individuals from Pabna (i.e., 79%) replied that they would sell any extra papaya. While in Rangpur, only 14% of those interviewed would see sell the extra papaya. Overall in both locations, approximately 57% would consume any extra papaya produced and 43% would sell extra papaya.

Bangladesh, with a land area of 147,570 km^2 and a population of approximately 150 million, is one of the most population dense countries in the world and with a gross national income per capita of only $450, it is also one of the poorest (U.S. Dept. of State, 2008; World Bank, 2008). Micronutrient malnutrition (e.g., vitamin A, iron (Fe), and zinc (Zn) deficiencies) is a significant nutritional problem in Bangladesh. These deficiencies have been associated with a higher incidence of mortality and morbidity, an increased risk of infection, reduced productivity, and impaired cognitive development and function in susceptible individuals (Welch, 2002). In Bangladesh, an estimated 30% of all preschool aged children are deficient in vitamin A (West, 2002). In addition, 45% of preschool aged children and women of reproductive age are deficient in Fe (FAO, 1999).

Ripe papaya is an important source of vitamin A (i.e., provitamin A carotenoids), vitamin C, and folate (Table 1-1) (USDA-ARS, 2007; IOM-NAS, 2004). For example, a small 150 gram serving of fresh papaya would provide 124%, 14%, and 12% of the RDA (i.e., 19 to 50 year-old female) for vitamin C, folate, and

Table 1-1. Nutritional composition of papaya (USDA-ARS, 2007; IOM-NAS, 2004).

Nutrient	Amount per 150g edible portion	% RDA for Female (19-50y)
Ca	36 mg	3.6
Fe	0.15 mg	0.8
Mg	15 mg	4.8
P	8 mg	1.1
K	386 mg	8.2
Na	4 mg	0.3
Zn	0.11 mg	1.4
Cu	0.024 mg	2.7
Mn	0.017 mg	0.9
Se	0.9 *ug*	1.6
Vitamin C	92.7 mg	123.6
Thiamin	0.041 mg	3.7
Riboflavin	0.048 mg	4.4
Niacin	0.507 mg	3.6
Pantothenic acid	0.327 mg	6.5
Vitamin B_6	0.028 mg	2.2
Folate	57 mg	14.3
Vitamin B_{12}	0 mg	0.0
Vitamin A	82 *ug* RAE	11.7
Vitamin E	1.09 mg	7.3
Vitamin K	3.9 *ug*	4.3

vitamin A, respectively (USDA-ARS, 2007; IOM-NAS, 2004). In addition, the consumption of vitamin C containing foods has the potential to increase Fe bioavailability and thus positively impact Fe status in deficient individuals.

Results from the Rangpur and Pabna household survey suggest that ripe papaya is commonly consumed by individuals in Bangladesh (J. King, unpublished data, 2005). When asked which members of their families consume ripe papaya, 97% of the respondents replied that all of their family members consume ripe papaya. Within these households, approximately 22% of those interviewed replied that children consumed the greatest amount of ripe papaya, 10% replied that adults consumed the most ripe papaya, and 68% replied that the family members consumed equal amounts of ripe papaya. In addition, 100% and 99% of those questioned replied that ripe papaya is consumed by infants and pregnant women, respectively. Ripe papaya tends to be consumed as a snack between meals as opposed to being consumed with the meals. For example, of those interviewed, 88% said that they consumed ripe papaya as a snack between meals, while only 17% consumed ripe papaya with the meal. When asked why does your family consume ripe papaya, the majority of respondents replied that they consumed papaya because it was good for them. In comparison, only 33% cited taste and 10% stated that they believed ripe papaya had medicinal value.

Green papaya is also widely consumed by individuals in Bangladesh. According to the survey, 96% of those questioned replied that everyone in their family consumed green papaya (J. King, unpublished data, 2005). When asked who consumed the greatest quantity of green papaya in their household, 16% replied that their children consumed the most green papaya, 21% replied that the adults consumed the greatest amount, and 62% stated that everyone in the family consumed equal portions. In addition, 97% and 100% of those interviewed replied that green papaya is consumed by infants and pregnant women, respectively. In contrast to the reasoning behind ripe papaya consumption, the majority of respondents replied that they consumed green papaya because of its medicinal value. In addition, 42% of those questioned replied that they consumed green papaya because it was good for them and 23% stated that they consumed green papaya because of the taste.

Even though the availability and production of cereals has increased over the last few decades in Bangladesh, the availability of fruits and vegetables has steadily declined from approximately 40 kg per person to 23 kg per person annually (FAO, 1999; Kiess et al., 2001). Both of these values are well below the recommended intake of at least 73 kg of fruits and vegetables per year (Welch and Graham, 1999). In addition, many fruits and vegetables in Bangladesh are only seasonally available (Monayem-Miah and Sabur, 1998). Therefore, an improvement in the production and availability of vitamin rich fruits and vegetables has the potential to positively impact the nutritional status of micronutrient deficient individuals in Bangladesh.

The overall objective of this study was to determine the effect of poultry manure, lime, and micronutrient application on plant nutrition, soil properties, fruit yield, and the vitamin content of papaya. In addition, the present study evaluated the impact of planting date and location on the production and availability of papaya in Bangladesh.

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CHAPTER TWO

EFFECT OF NUTRIENT MANAGEMENT AND PLANTING DATE ON PLANT NUTRITION, SOIL FERTILITY, AND PAPAYA YIELD IN RANGPUR

Introduction

Papaya (*Carica papaya*) can be cultivated on a wide range of soils, but prefers soil with a pH between 5.0 and 7.0. In Hawaii, the application of lime is generally recommended when the soil pH ≤ 5.5 and especially if the soil concentration of aluminum (Al) or manganese (Mn) is high (Nishina et al., 2000). In earlier studies, the application of lime to acidic soil was shown to improve papaya yield (Nakasone and Paull, 1998; Awada et al., 1975). In fact, results from an experiment in Hawaii suggest that the application of lime has the potential to increase papaya yield seven-fold as compared to non-amended plots (Younge and Plucknett, 1964).

In a study by Marler (1998), papaya seedlings were grown in plastic tubes with a solution pH that ranged from 3.0 to 9.0. At the completion of the experiment, the dry weight of the seedlings was generally unchanged at pH ≥ 4.0. This author suggests that the negative effect of acidic soils on papaya growth is most likely related to other soil characteristics besides low pH (Marler, 1998). Marler and dela Cruz (2001) conducted an experiment to determine the cause of reduced papaya growth in acid soils. In this study, seedlings were placed in containers with one of four treatments: control, with $CaSO_4$, with MgO, and with $Ca(OH)_2$. It was assumed that $CaSO_4$ supplied calcium (Ca), but did not impact soil Al, MgO did not supply Ca, but lowered soil Al, and $Ca(OH)_2$ supplied Ca and lowered soil Al. The results from this study suggest that both Al toxicity and Ca deficiency can decrease papaya root growth (Marler and Cruz, 2001). Adequate levels of Ca in the papaya plant are particularly important for papaya ripening and are therefore necessary to ensure quality of the fruit (Qiu et al., 1995). Due to the acidic nature of the soil in Rangpur, Bangladesh (i.e., pH 4-5), one of the objectives of this study was to evaluate the effect of lime applications on soil properties, plant nutrition, and papaya yield.

Organic amendments (e.g., animal manures and crop residues) have the potential to increase the organic matter content of the soil. An improved soil organic matter content is generally associated with reduced bulk density, increased water holding capacity, and improved fertility and quality of the soil (Brady and Weil, 1996). For these reasons, organic amendments have the potential to increase crop yield (Weil and Magdoff, 2004). Results from a study in Australia determined that the application of a coarse grass hay mulch increased the stem growth and plant height of papaya (Elder et al., 2000). In addition, this grass hay mulch improved papaya yield by 50% (Elder et al., 2000). Results from a household survey from Rangpur determined that 95% of respondents applied organic fertilizer (e.g., poultry manure, cow dung, and household waste) to papaya plants in their home gardens (J. King, unpublished data, 2005). In comparison, only 47% of those questioned applied inorganic fertilizer (e.g., urea, triple super phosphate). Of those respondents with only six or fewer papaya plants in their home gardens, approximately 60% either did not apply any fertilizer or only applied organic fertilizer. Therefore, because of the importance of organic amendments to papaya production in this area, an additional objective of this study was to determine the effect of poultry manure applications on soil properties, plant nutrition, and papaya yield.

In Bangladesh, even though the availability and production of cereals has increased over the last few decades, the availability of fruits and vegetables has steadily declined from approximately 40 kg per person to 23 kg per person annually (FAO, 1999; Kiess et al., 2001). Besides the overall reduced availability of these foods, many of the fruits and vegetables are only available during certain times of the year in Bangladesh. For example, popular fruits such as lychee (*Litchi chinensis*), mango (*Mangifera indica*), and jackfruit (*Artocarpus heterophyllus*) are only available between May and June (Monayem-Miah and Sabur, 1998).

In addition, acute human malnutrition also tends to vary seasonally throughout the year in Bangladesh. For example, the prevalence of micronutrient malnutrition (e.g., vitamin A, iodine (I), iron (Fe), and zinc (Zn) deficiencies) tends to be highest between June and August and lowest during the winter months. In the winter, the summer rice (*Oryza sativa*) has been harvested and vegetables are more readily available in the market (FAO, 1999). Overall, at least 50% of all children and women of reproductive age are deficient in vitamin A and iron in rural Bangladesh (Talukder et al., 2000). This lack of availability of fruits and vegetables is most likely contributing to micronutrient malnutrition in Bangladesh.

Papaya has the potential to produce fruit year-round and is an important source of vitamin A (i.e., provitamin A carotenoids), vitamin C, and folate (Manshardt, 1992; USDA-ARS, 2007). The overall objective of this study was to evaluate the effect of lime, poultry manure, and planting date on plant nutrition, soil fertility, and papaya production and availability in Rangpur, Bangladesh.

Materials and Methods

Between fall 2004 and spring 2006, three field experiments were conducted at the On Farm Research Division, Bangladesh Agricultural Research Institute in Rangpur, Bangladesh. For the first and second experiments in Rangpur, eight week old papaya seedlings were transplanted in April 2004 and October 2004, respectively. The experiments were situated adjacent to each other at the research station. In Bangladesh, papaya seedlings are traditionally transplanted in March or April, and therefore the second Rangpur experiment (OCT 2004) represents an alternate planting date for papaya cultivation. Unfortunately, during fall 2004, some of the papaya plants from the first Rangpur experiment (APR 2004) were damaged from high winds and the experiment was terminated approximately 3 months early (i.e., December 2004). A third experiment in Rangpur was initiated in April 2005 on the same site as the first Rangpur (APR 2004) experiment. There is only one papaya variety (i.e., 'Shahi') in Bangladesh. Unfortunately, due to damage from disease and hail, 'Shahi' papaya seed is currently unavailable for cultivation (N. Islam, personal communication, 2004). Therefore, for the first (APR 2004) Rangpur experiment, papaya seed was collected instead from a large papaya grower in Ishurdi, Bangladesh. For the second (OCT 2004) and third (APR 2005) Rangpur experiments, papaya seed was obtained from a large papaya grower in Rangpur. The soil at this location (Bangladesh soil series 'Gongachara') was a silt loam with approximately 40% sand and an acidic pH of 4.0 to 4.7. A description of the initial soil characteristics for first (APR 2004) and second (OCT 2004) Rangpur experiments are detailed in Table 2-1.

For the first (APR 2004), second (OCT 2004), and the third (APR 2005) Rangpur experiments, the treatments were the same and were as follows: treatment one received chemical fertilizer only, treatment two received an additional 1.0 t ha^{-1} dolomite, treatment three received 21 t ha^{-1} poultry manure (i.e., 10 kg poultry manure $plant^{-1}$), and lastly, treatment four received both 21 t ha^{-1} poultry manure and 1.0 t ha^{-1} dolomite. These treatments are referred to as base fertilizer (BF), BF + Lime, BF + Manure, and BF + Lime + Manure. For the first (APR 2004) and second (OCT 2004) Rangpur experiments, each plot received 533 kg N ha^{-1}, 186 kg P ha^{-1},

Table 2-1. Pre-plant soil characteristics of Rangpur experiment (APR 2004) and Rangpur experiment (OCT 2004) located at Rangpur OFRD, Bangladesh.

Property Analyzed	Rangpur Experiment (APR 2004)	Rangpur Experiment (OCT 2004)
	mg kg^{-1}	
Total N	671 ± 32†	620 ± 38
Morgan P	5.3 ± 1.4	6.9 ±1.8
Morgan K	68 ± 3.7	54 ± 1.0
Morgan Ca	134 ± 37.0	76 ± 24.0
Morgan Mg	16.1 ± 2.3	8.9 ± 3.7
DTPA Cu	1.37 ± 0.08	1.44 ± 0.19
DTPA Mn	6.56 ± 0.50	5.05 ± 0.23
DTPA Zn	0.74 ± 0.08	0.68 ± 0.04
DTPA Fe	59.89 ± 11.91	65.31 ± 15.00
DTPA Ni	0.02 ± 0.01	0.02 ± 0.01
Morgan Al	96.7 ± 5.8	95.4 ± 4.2
	%	
Total C	0.95 ± 0.06	0.89 ± 0.08
pH	4.55 ± 0.44	4.25 ± 0.07

† Data calculated from four replications and standard deviation, respectively.

442 kg K ha^{-1}, 72 kg S ha^{-1}, 7.7 kg Zn ha^{-1}, and 4.7 kg B ha^{-1} each year from urea, triple super phosphate, muriate of potash, gypsum, zinc sulfate, and borax, respectively. For the third (APR 2005) Rangpur experiment, each plot received the same fertilizer regime as the other Rangpur experiments with the exception that the B fertilizer application was reduced by one-half (i.e., 2.3 kg B ha^{-1}). For all of the experiments, urea and muriate of potash were applied monthly, triple super phosphate and poultry manure were applied every six months, and the remainder of the fertilizer was applied prior to transplanting. For the first (APR 2004) Rangpur experiment, poultry manure from sample lot A was applied prior to transplanting and then again after six months. For the second (OCT 2004) and third (APR 2005) Rangpur experiments, poultry manure from sample lot A was applied prior to transplanting and the second application from sample lot B was applied after six months. The nutrient concentration for each of the sample lots of manure was determined (Table 2-2). Due to the very acidic pH at this location and also the importance of Ca for the ripening of papaya fruit, a supplemental Ca fertilizer application of 0.2 t ha^{-1} dolomite was applied to treatments one and three (Qiu et al., 1995; Nishina et al., 2000).

Prior to planting, fertilizer was placed in a round pit that had a diameter of 80 cm and a depth of 40 cm. The fertilizer was incorporated into the soil and then the soil was formed into a mound. Three approximately eight week old seedlings were transplanted onto each mound. About two months after transplanting, excess male and hermaphrodite plants were removed to leave one plant per mound for a total of nine plants per plot. Fertilizer that was applied after transplanting was placed in a ring around each plant at a depth of approximately 5 cm and then covered with surrounding soil.

Table 2-2. Analysis of poultry manure collected from Gazipur, Bangladesh.

Property Analyzed	Sample Lot A	Sample Lot B
	Total Element Concentration	
	---------- $g\ kg^{-1}$ ----------	
N	9.9 ± 0.4†	6.7 ± 0.8
P	13.7 ± 4.5	2.7 ± 0.5
K	6.7 ± 0.8	5.9 ± 0.7
Ca	160.8 ± 17.6	119.0 ± 21.5
Mg	10.6 ± 0.8	7.5 ± 0.3
	---------- $mg\ kg^{-1}$ ----------	
Cu	70.0 ± 6.5	74.6 ± 8.5
Mn	102.5 ± 44.9	1116.8 ± 565.6
Zn	259.7 ± 76.0	217.1 ± 22.0
Fe	1227.1 ± 745.6	833.4 ± 767.4
Mo	0.26 ± 0.14	0.45 ± 0.05
	----------	----------
C:N	10.8 ± 0.5	16.3 ± 1.1
	---------- % ----------	
C	10.7 ± 0.9	10.9 ± 1.7
Dry matter	69.7 ± 1.0	64.6 ± 3.7

† Data calculated from four replications and standard deviation, respectively.

Table 2-3. Description of field experiments that were conducted from 2004 to 2006 at Rangpur OFRD, Bangladesh.

Name:	Rangpur Experiment (APR 2004)	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)
Design:	RCB	RCB	RCB
Replications:	4	4	4
Plot size:	36 m^2	36 m^2	36 m^2
Plants $plot^{-1}$:	9	9	9
Transplant Date:	April 2004	October 2004	April 2005
Treatments:			
1	BF	BF	BF
2	BF + Lime	BF + Lime	BF + Lime
3	BF + Manure	BF + Manure	BF + Manure
4	BF + Manure + Lime	BF + Manure + Lime	BF + Manure + Lime

For all of the experiments, the experimental design was a randomized complete block design with four replications. The plant spacing was two meters between rows and two meters between plants in a row. Each plot consisted of nine plants for a total plot size of 36 m^2. In addition, an extra one-half meter between plots was allotted to minimize any potential border effects among plots. The description and experimental design for each of these experiments are summarized in Table 2-3.

Papaya fruit was harvested at the color break stage from September 2004 to December 2004 for the first (APR 2004) Rangpur experiment, from August 2005 to March 2006 for the second (OCT 2004) Rangpur experiment, and from October 2005 to early April 2006 for the third (APR 2005) Rangpur experiment. For the first (APR 2004) Rangpur experiment, plant girth for each plant was measured at 50 cm height in September 2004. For the second (OCT 2004) Rangpur experiment, plant girth and plant height were measured in June 2005, August 2005, October 2005, and December 2005. For the third (APR 2005) Rangpur experiment, plant girth and plant height were measured in September 2005, November 2005, January 2006, and March 2006.

For soil analyses, soil samples were collected before transplanting and after harvest for each experiment. Nine cores from every plot were collected with a soil augur (4 cm in diameter and 18 cm in length) from 0 to 20 cm depth. The soil was mixed and a representative soil sample was obtained. In order to determine the soil concentration of P, K, Ca, Mg, and Al, available nutrients were extracted with Morgan's solution (i.e., sodium acetate/acetic acid solution) (Morgan, 1941). In order to determine the soil micronutrient (i.e., Cu, Mn, Zn, Fe, Ni) concentration, soil samples were extracted with the diethylenetriaminepentaacetic acid – triethanolamine (DTPA-TEA, pH 7.3) method (Lindsay and Norvell, 1978). All samples were then analyzed by inductively coupled plasma atomic emission spectroscopy (Spectro Ciros CCD ICP, Germany). Soil pH was determined by preparing a 2:1 deionized water: soil mixture and then analyzing the mixture using a pH electrode.

In order to determine leaf nutrient concentrations, three petiole samples under the most recently set fruit were collected per plot (Nishina et al., 2000). For the first (APR 2004) Rangpur experiment, petioles were collected during September 2004. For the second (OCT 2004) Rangpur experiment, petiole samples were obtained in August and October 2005. For the third (APR 2005) Rangpur experiment, petiole samples were collected in September 2005 and November 2005. The petioles were dried at 70˚C for 72 hours, the sample dry weight was recorded, and then the samples were ground using a Wiley Mill. In order to determine the nutrient concentration of the poultry manure, 4 samples were collected from a sample lot. The manure samples were dried at 60˚C for 72 hours and ground using a Wiley Mill. For both leaf petiole and manure samples, 0.5 g sample was placed in a glass tube with 3.0 mL concentrated HNO_3 solution on a digestion block overnight at room temperature. An additional 1.0 mL of HNO_3 was added and the samples were slowly heated to 100˚C over 2.5 hours. After which, an additional 2.0 mL HNO_3 was added and the samples were digested at 130˚C for approximately 20 hours. The temperature of the samples was then raised to 145˚C for approximately six hours or until the sample had completely dried. Afterwards, 2 mL of H_2O_2 was added to the sample and then dried. After drying, another 2 mL of H_2O_2 was added. After the sample had been completely dried, the tubes were removed from the digestion block. Samples were then dissolved in 10 mL 5% HNO_3 and the concentration of P, K, Ca, Mg, Cu, Mn, Zn, Fe, and Mo was determined by inductively coupled plasma (ICP) atomic emission spectroscopy (Spectro Ciros CCD ICP, Germany).

In order to evaluate the carbon (C) and nitrogen (N) content of the soil, petiole, and poultry manure samples, each of the samples was first ball-milled. After milling, the total C and N was determined by dry combustion using an Europa Scientific Roboprep C/N analyzer (Nelson and Sommers, 1996). An analysis of variance was conducted on the data and mean separation was obtained with Duncan's New Multiple Range Test using MSTAT (Freed et al., 1993).

Results and Discussion

In this study, the application of an organic amendment (i.e., poultry manure) substantially increased yield as compared to the non-amended plots for the second (OCT 2004) and third (APR 2005) Rangpur experiments (Table 2-4 and Table 2-5). There were not any significant differences among treatments for papaya yield for the first (APR 2004) experiment (Table 2-4 and Table 2-5). For the second (OCT 2004) Rangpur experiment, the application of manure almost doubled the yield. For the third (APR 2005) Rangpur experiment, the application of manure more than doubled the papaya yield. For plants that received manure, the yield was slightly higher for the third (APR 2005) Rangpur experiment as compared to the second (OCT 2004) experiment in Rangpur. For example, when manure was applied, plants from the third Rangpur experiment yielded 26 to 28 kg per plant while plants from the second Rangpur experiment yielded approximately 22 to 24 kg per plant (Table 2-4).

In addition, for the plots that did not receive manure (i.e., treatments one and two), more fruit was produced per plant for the second (OCT 2004) Rangpur experiment as compared to the third (APR 2005) Rangpur experiment (Table 2-5). For example, in the second (OCT 2004) Rangpur experiment, papaya plants from treatments one and two produced approximately 19 to 21 fruit per plant. While in

Table 2-4. Effect of lime and poultry manure on papaya yield for Rangpur experiment (APR 2004), Rangpur experiment (OCT 2004), and Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	Rangpur Experiment (APR 2004)	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)
	---------------------------	kg plant^{-1}	------------------------------
BF	16.3†	10.8 b	8.8 b
BF + Lime	14.6	13.6 b	10.1 b
BF + Manure	20.3	23.8 a	26.0 a
BF + Manure + Lime	23.2	22.2 a	28.1 a

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-5. Effect of lime and poultry manure on the quantity of fruit produced for Rangpur experiment (APR 2004), Rangpur experiment (OCT 2004), and Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	Rangpur Experiment (APR 2004)	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)
	----------------------	no. of fruit plant^{-1}	-------------------------
BF	24†	19 b	12 b
BF + Lime	21	21 b	13 b
BF + Manure	27	33 a	31 a
BF + Manure + Lime	32	31 a	33 a

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

the third (APR 2005) Rangpur experiment, papaya plants only yielded 12 to 13 fruit per plant. When manure was applied (i.e., treatments three and four), the plants produced about the same quantity of fruit (e.g., 31-33 fruit per plant) irrespective of the planting date. Papaya plants from the second (OCT 2004) Rangpur experiment were transplanted six months before the papaya plants from the third (APR 2005) Rangpur experiment, and therefore it might be expected for these plants to produce more fruit. Even though there was a large yield response from poultry manure application, there were not any differences among treatments for the size of the papaya fruit. Under these research conditions, the fresh weight of the papaya ranged from approximately 0.60 to 0.90 kg (Table 2-6).

For the second (OCT 2004) experiment in Rangpur, the harvest of ripe papaya began in August 2005 as compared to September and October for the first (APR 2004) and third (APR 2005) Rangpur experiments, respectively (Figure 2-1, Figure 2-2, Figure 2-3, Figure 2-4, Figure 2-5, and Figure 2-6). Therefore, fall planting provided ripe papaya approximately four to eight weeks earlier than papaya plants that were transplanted at the traditional time (i.e., March and April). Since acute human malnutrition tends to be highest during June through August in Bangladesh, fall planting of papaya would provide vitamin A at a critical time during the year (FAO, 1999).

For Rangpur experiment (APR 2004), the production of papaya peaked in October (Figure 2-1 and Figure 2-2). However, this experiment was damaged by high winds which may have accelerated fruit ripening. Depending upon the treatment, fruit production for Rangpur experiment (APR 2005) peaked in either November or December (Figure 2-5 and Figure 2-6). Papaya plants that were transplanted in October tended to have the greatest production during the following

Table 2-6. Effect of lime and poultry manure on mean fruit weight for Rangpur experiment (APR 2004), Rangpur experiment (OCT 2004), and Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	Rangpur Experiment (APR 2004)	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)
	----------------------------	kg	--------------------------------
BF	0.71†	0.58	0.80
BF + Lime	0.74	0.68	0.82
BF + Manure	0.79	0.72	0.90
BF + Manure + Lime	0.80	0.75	0.89

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

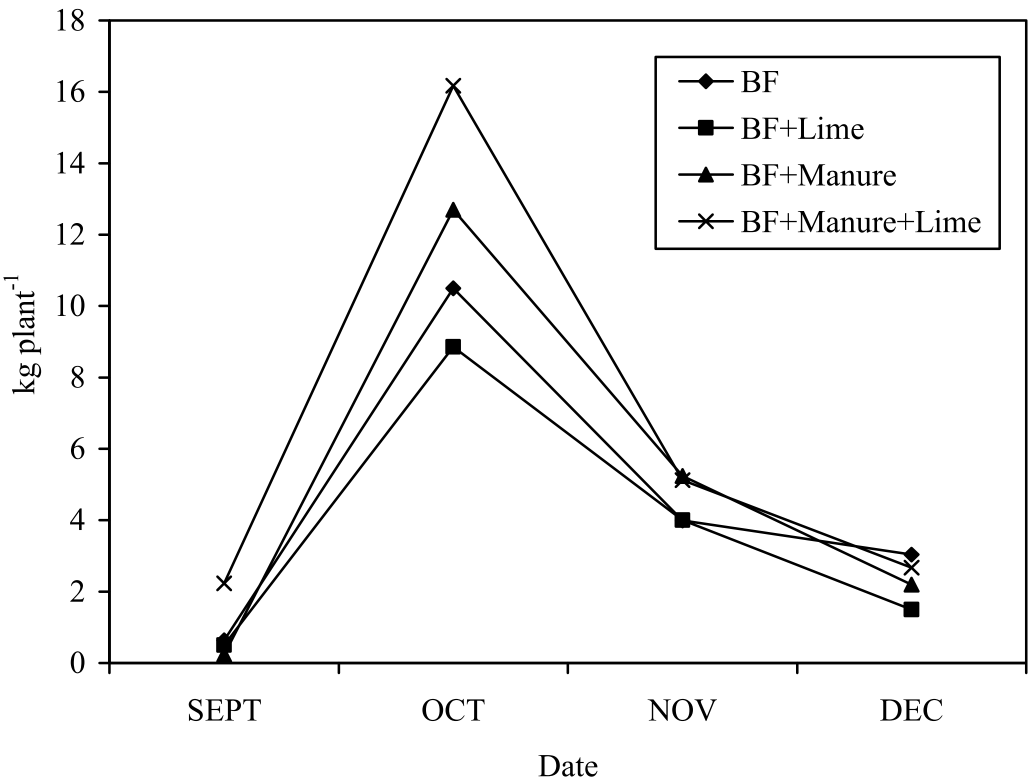

Figure 2-1. Effect of lime and poultry manure on papaya yield over time for Rangpur experiment (APR 2004) located at Rangpur OFRD, Bangladesh.

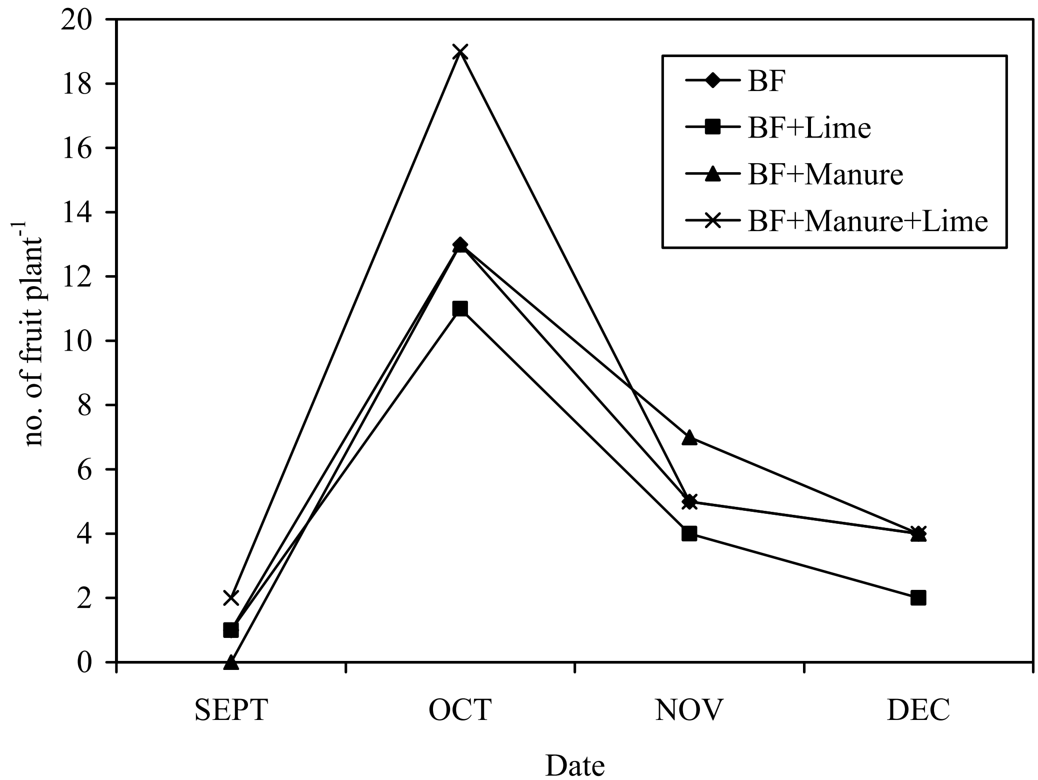

Figure 2-2. Effect of lime and poultry manure on the quantity of papaya produced over time for Rangpur experiment (APR 2004) located at Rangpur OFRD, Bangladesh.

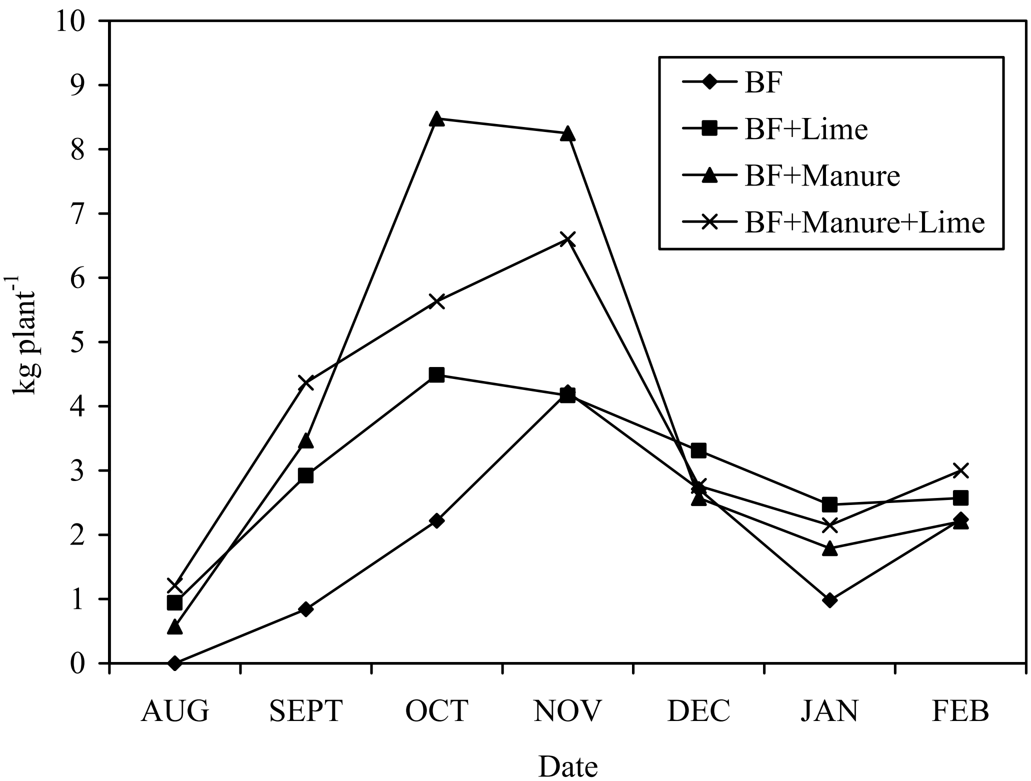

Figure 2-3. Effect of lime and poultry manure on papaya yield over time for Rangpur experiment (OCT 2004) located at Rangpur OFRD, Bangladesh.

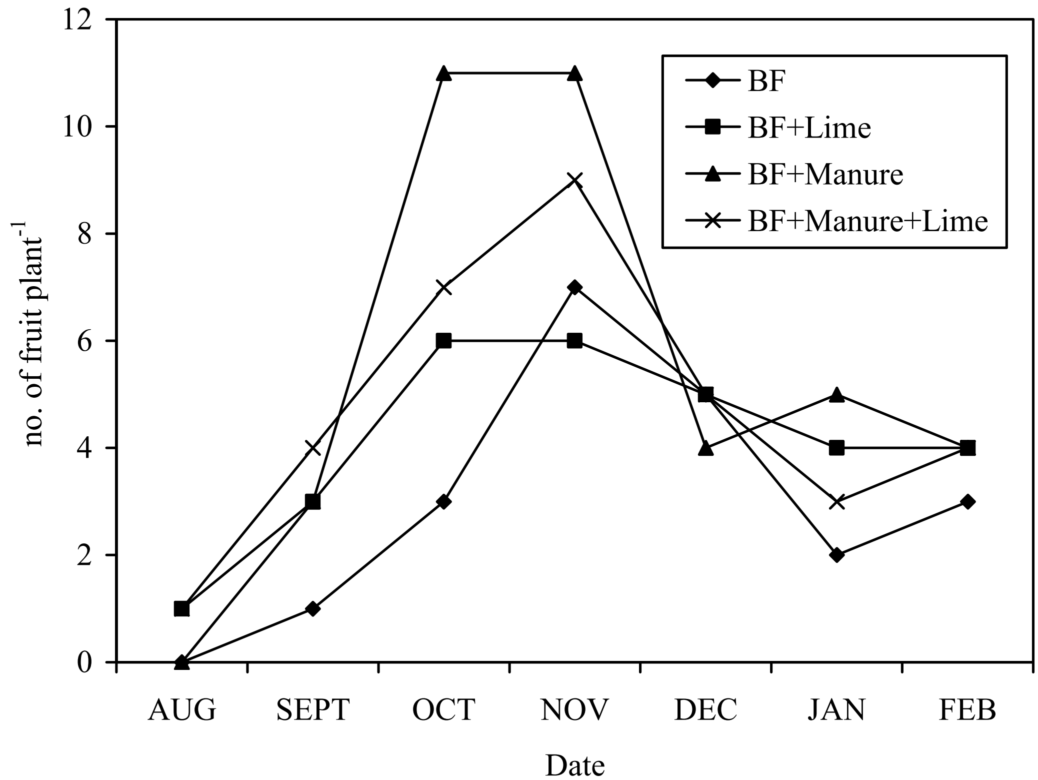

Figure 2-4. Effect of lime and poultry manure on the quantity of papaya produced over time for Rangpur experiment (OCT 2004) located at Rangpur OFRD, Bangladesh.

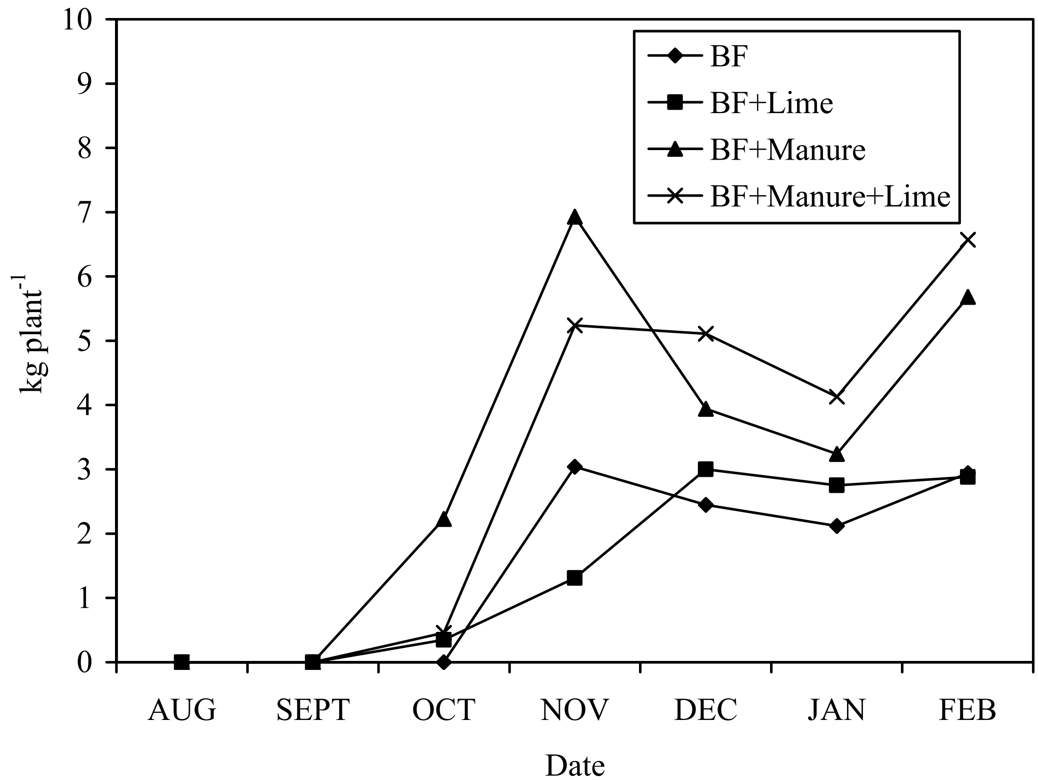

Figure 2-5. Effect of lime and poultry manure on papaya yield over time for Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

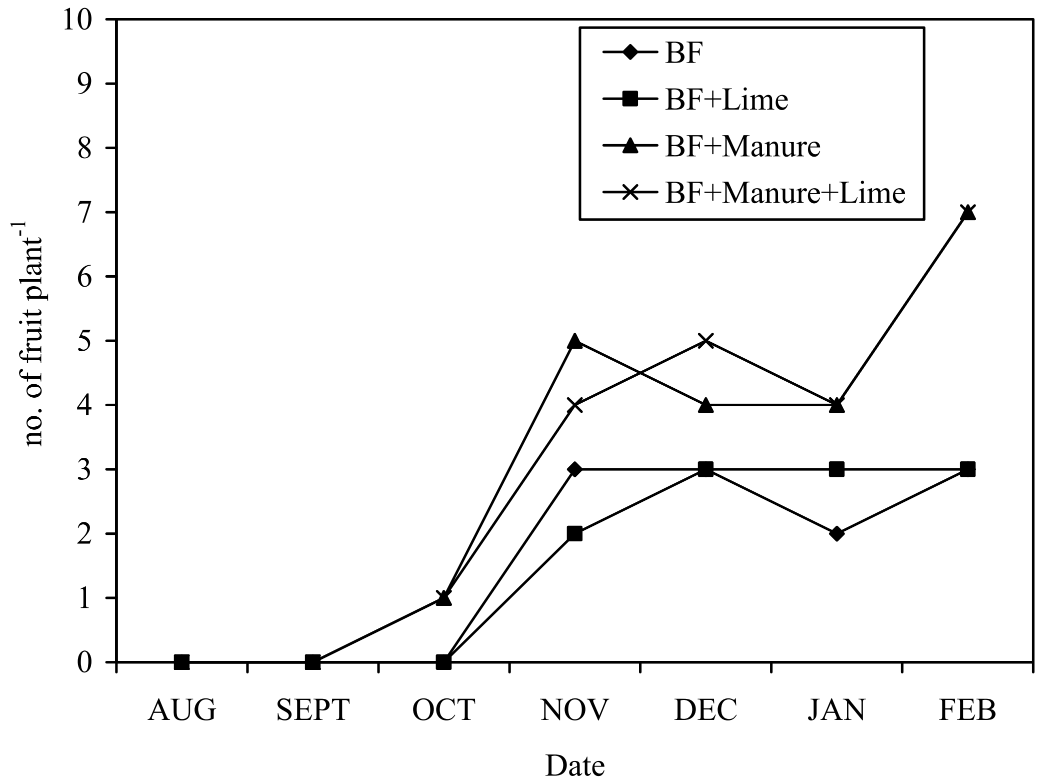

Figure 2-6. Effect of lime and poultry manure on the quantity of papaya produced over time for Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

October and November (Figure 2-3 and Figure 2-4). All of the experiments exhibited a decrease in papaya production during the winter months. Interestingly, Rangpur experiment (APR 2005) showed an improvement in production in February. This improvement was not evident for Rangpur experiment (OCT 2004). Overall, when papaya fruit production was averaged across all treatments, papaya that was transplanted in October produced a greater amount of fruit earlier than papaya which was transplanted in April (Figure 2-7 and Figure 2-8).

The application of lime did not improve the amount and/or quantity of papaya produced for any of the Rangpur experiments (Table 2-4 and Table 2-5). It is possible that a much greater application rate of lime is necessary to increase papaya yield under these conditions. Even though the addition of lime did not significantly affect papaya yield, there was a small response from lime on papaya growth early in the growing season. For example, the application of lime increased the plant height during June 2005 for the second (OCT 2004) Rangpur experiment (Table 2-7). In addition, the lime application improved plant girth in September 2004 for the first (APR 2004) Rangpur experiment, in June 2005 for the second (OCT 2004) Rangpur experiment, and in September 2005 for the third (APR 2005) Rangpur experiment (Table 2-9, Table 2-10, and Table 2-11).

In comparison, the application of poultry manure impacted both plant height and girth. For the first (APR 2004) experiment, the plant girth in September 2004 was statistically larger from manure application (Table 2-9). For the second (OCT 2004) Rangpur experiment, plant height and girth were statistically greater in June, August, October, and December 2005 for the plots which received additions of poultry manure (Table 2-7 and Table 2-10). Similarly, plant height and girth were also greater after manure application for the third (APR 2005) experiment in September 2005, November 2005, January 2006, and March 2006 (Table 2-8 and

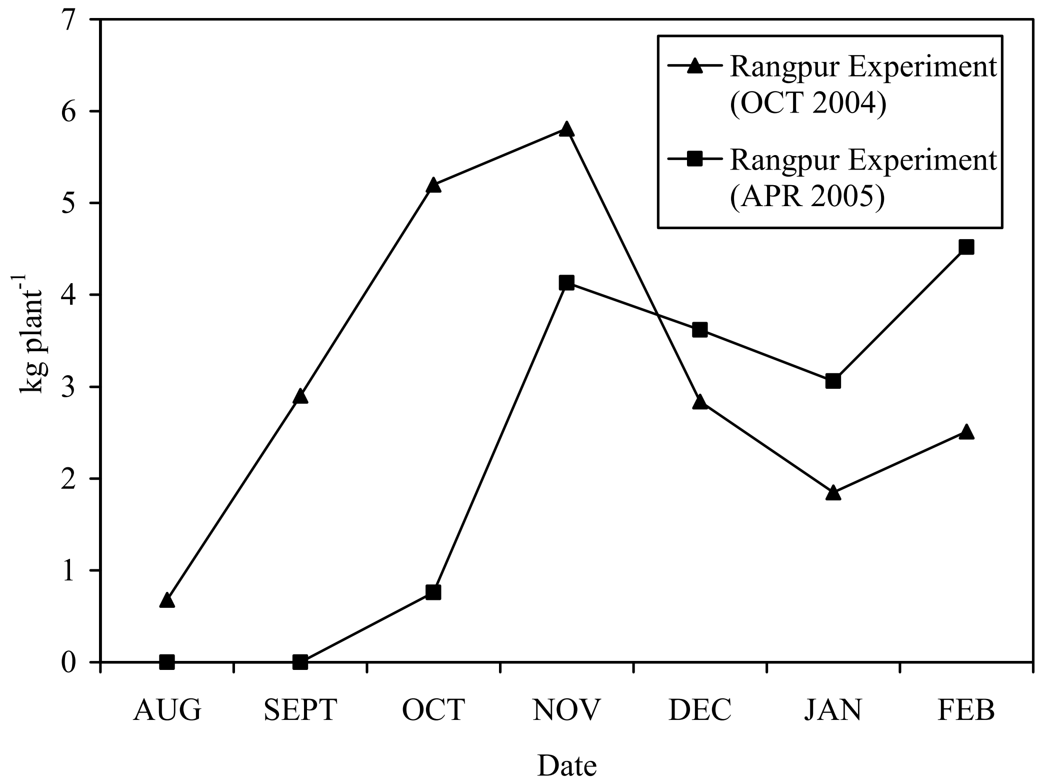

Figure 2-7. Papaya yield over time for Rangpur experiment (OCT 2004) and Rangpur experiment (APR 2005) averaged across all treatments at Rangpur OFRD, Bangladesh.

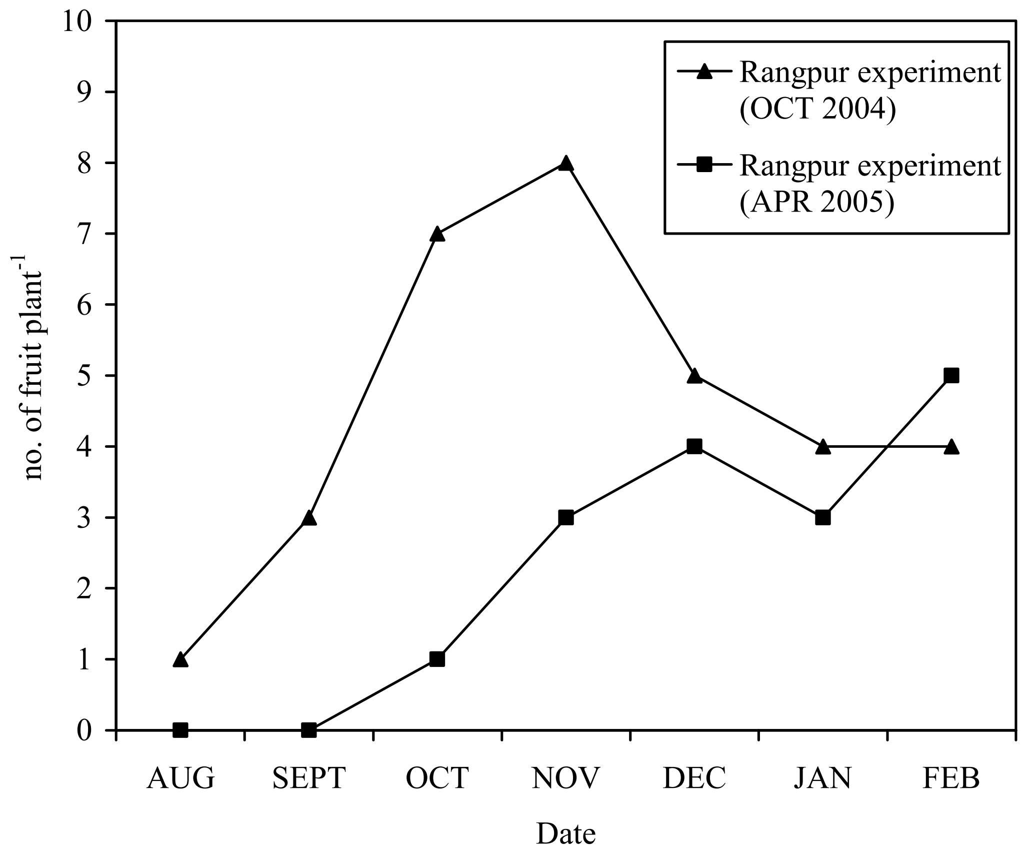

Figure 2-8. Quantity of papaya produced over time for Rangpur experiment (OCT 2004) and Rangpur experiment (APR 2005) averaged across all treatments at Rangpur OFRD, Bangladesh.

Table 2-7. Effect of lime and poultry manure on plant height for Rangpur experiment (OCT 2004) located at Rangpur OFRD, Bangladesh.

Treatment	June 2005	August 2005	October 2005	December 2005
	-------------------------------	m	--------------------------------------	
BF	0.89 c†	1.47 b	1.62 b	1.62 b
BF + Lime	1.04 b	1.57 b	1.63 b	1.65 b
BF + Manure	1.43 a	1.88 a	1.95 a	1.98 a
BF + Manure + Lime	1.35 a	1.86 a	1.90 a	1.96 a

† Within each column, means followed by the same letter are not different at p≤0.05 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-8. Effect of lime and poultry manure on plant height for Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	September 2005	November 2005	January 2006	March 2006
	----------------------------------	m	------------------------------	
BF	1.59 b†	1.73 b	1.69 b	1.81 b
BF + Lime	1.71 b	1.87 b	1.83 b	1.99 b
BF + Manure	2.30 a	2.37 a	2.26 a	2.44 a
BF + Manure + Lime	2.38 a	2.48 a	2.42 a	2.56 a

† Within each column, means followed by the same letter are not different at p≤0.05 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-9. Effect of lime and poultry manure on plant girth for Rangpur experiment (APR 2004) located at Rangpur OFRD, Bangladesh.

Treatment	September 2004
	---------- cm ----------
BF	15.3 c†
BF + Lime	16.5 c
BF + Manure	18.8 b
BF + Manure + Lime	20.5 a

† Means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-10. Effect of lime and poultry manure on plant girth for Rangpur experiment (OCT 2004) located at Rangpur OFRD, Bangladesh.

Treatment	June 2005	August 2005	October 2005	December 2005
	----------	----------	cm ----------	----------
BF	8.5 c†	12.6 b	15.1 b	15.5 b
BF + Lime	10.5 b	13.5 b	15.2 b	15.4 b
BF + Manure	15.6 a	17.1 a	18.3 a	19.9 a
BF + Manure + Lime	14.3 a	16.9 a	18.5 a	19.2 a

† Within each column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-11. Effect of lime and poultry manure on plant girth for Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	September 2005	November 2005	January 2006	March 2006
	----------	----------	cm ----------	----------
BF	13.3 c†	14.5 b	14.9 b	15.1 b
BF + Lime	14.8 b	16.2 b	16.7 b	16.9 b
BF + Manure	22.2 a	25.0 a	25.0 a	25.4 a
BF + Manure + Lime	22.8 a	25.3 a	25.6 a	25.6 a

† Within each column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-11). Additionally, the petiole weight for the first (APR 2004) and the third (APR 2005) Rangpur experiments tended to be higher when manure was applied (Table 2-12 and Table 2-14). Petiole weight was generally not affected by any of the treatments for the second (OCT 2004) experiment (Table 2-13). Overall, the papaya plants that were transplanted in the spring were slightly larger (i.e., tree girth and plant height) as compared to plants that were transplanted in the fall (Table 2-7, Table 2-8, Table 2-9, Table 2-10, and Table 2-11).

For all of the experiments, the soil concentration of total N and Morgan K was not affected by any treatment (Table 2-15). In the second (OCT 2004) Rangpur experiment, the soil Cu and Ni content were slightly higher from manure application (Table 2-16). Otherwise, soil Cu and Ni were not affected by any of the treatments for the other experiments. For the third (APR 2005) Rangpur experiment, the concentration of soil Mn tended to be higher and soil Fe was lower from the addition of poultry manure. There were not any significant differences among treatments for soil Mn and Fe for the other experiments. However, in general, the application of poultry manure increased the soil concentration of P, Ca, Mg, and Zn for each experiment (Table 2-15; Table 2-16).

For treatments one and two, the P content of the soil was two times greater than the pre-plant values (Table 2-1 and Table 2-15). When both manure and chemical fertilizer were added, the P content was approximately ten times higher than the initial values for all of the experiments (Table 2-1 and Table 2-15). Depending upon the experiment, the application of poultry manure increased soil Ca by two to five times as compared to plots that did not receive manure (Table 2-15). On average, soil Ca content increased from 325 to 1075 mg kg^{-1} from manure

Table 2-12. Effect of lime and poultry manure on the petiole weight for Rangpur experiment (APR 2004) located at Rangpur OFRD, Bangladesh.

Treatment	Sampled: September 2004	
	---------- g ----------	
	Fresh wt	Dry wt
BF	111 c†	13 c
BF + Lime	119 c	14 c
BF + Manure	152 b	18 b
BF + Manure + Lime	184 a	21 a

† Within each column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-13. Effect of lime and poultry manure on the petiole weight for Rangpur experiment (OCT 2004) located at Rangpur OFRD, Bangladesh.

Treatment	Sampled: August 2005		Sampled: October 2005	
	---------- g ----------			
	Fresh wt	Dry wt	Fresh wt	Dry wt
BF	57†	7	46	7 b
BF + Lime	73	9	60	9 ab
BF + Manure	92	10	80	11 a
BF + Manure + Lime	102	11	60	6 b

† Within each column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-14. Effect of lime and poultry manure on the petiole weight for Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	Sampled: September 2005		Sampled: November 2005	
	---------- g ----------			
	Fresh wt	Dry wt	Fresh wt	Dry wt
BF	85 b†	11 b	72 b	7
BF + Lime	107 b	12 b	80 b	5
BF + Manure	183 a	22 a	117 a	11
BF + Manure + Lime	201 a	24 a	100 ab	7

† Within each column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

application. The soil Ca content also tended to be greater in the plots that received lime (i.e., treatments two and four). However, the soil Ca content was only significantly higher after lime application in the second (OCT 2004) Rangpur experiment (Table 2-15).

The concentration of soil Mg was also affected by both the poultry manure and the lime treatments (Table 2-15). Soil Mg increased with both the lime and poultry manure treatment. However, the poultry manure had a larger effect on the soil Mg content for all of the experiments. The addition of poultry manure increased soil Mg from approximately 35 to 95 mg kg^{-1} (Table 2-15). In addition, the concentration of soil Zn increased from approximately 0.70 mg kg^{-1} at the beginning of the experiment to as much as 6.70 mg kg^{-1}, depending upon the treatment and experiment, at the end of the study (Table 2-16).

For all of the experiments in Rangpur, the application of poultry manure lowered the concentration of Al in the soil (Table 2-17). The lime amendment also lowered the soil Al concentration (Table 2-17). However, the poultry manure, on average, reduced soil Al by 55 mg kg^{-1}, while the lime treatment only lowered the soil Al content by approximately 15 mg kg^{-1}. When manure was added, the application of lime increased the soil pH for the second (OCT 2004) and third (APR 2005) Rangpur experiments (Table 2-17). However, for each experiment, the largest increase in soil pH resulted from poultry manure application (Table 2-17).

The nutrient concentration of the poultry manure used in this study was generally within the typical range described for animal manures, with the exception that the concentration of Mn and Ca were slightly higher than published values (Havlin et al., 2005). For example, a typical Mn concentration of animal manure is approximately 0.01 to 0.05 %. For the poultry manure used in this study, the manure ranged from 0.01 to 0.11 %. Likewise for Ca, typical values in animal manure range

Table 2-15. Effect of lime and poultry manure on the macronutrient concentration of soil samples collected after harvest for Rangpur experiment (APR 2004), Rangpur experiment (OCT 2004), and Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	Rangpur Experiment (APR 2004)	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)
	------------------------------	$mg\ kg^{-1}$	------------------------------
		Total N	
BF	722†	741	866
BF + Lime	756	725	890
BF + Manure	716	759	930
BF + Manure + Lime	843	866	928
		Morgan P	
BF	11 b	14 b	18 b
BF + Lime	12 b	13 b	22 b
BF + Manure	64 a	45 a	69 a
BF + Manure + Lime	63 a	68 a	77 a
		Morgan K	
BF	122	211	333
BF + Lime	123	197	355
BF + Manure	128	186	351
BF + Manure + Lime	123	161	286
		Morgan Ca	
BF	521 b	230 c	222 b
BF + Lime	569 b	211 c	295 b
BF + Manure	1231 a	806 b	1179 a
BF + Manure + Lime	1368 a	1209 a	1399 a
		Morgan Mg	
BF	48 d	28 c	29 c
BF + Lime	87 c	33 c	42 c
BF + Manure	119 b	85 b	82 b
BF + Manure + Lime	144 a	123 a	114 a

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-16. Effect of lime and poultry manure on the micronutrient concentration of soil samples collected after harvest for Rangpur experiment (APR 2004), Rangpur experiment (OCT 2004), and Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	Rangpur Experiment (APR 2004)	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)
		mg kg^{-1}	
		DTPA Cu	
BF	1.45†	1.71 b	1.52
BF + Lime	1.59	1.72 b	1.64
BF + Manure	1.57	1.91 a	1.63
BF + Manure + Lime	1.56	1.82 ab	1.61
		DTPA Mn	
BF	14.22	11.87	14.62 b
BF + Lime	12.31	10.90	16.38 b
BF + Manure	11.80	10.50	23.43 a
BF + Manure + Lime	10.83	10.07	20.52 ab
		DTPA Zn	
BF	3.79	1.53 c	2.79 b
BF + Lime	3.22	1.42 c	3.18 b
BF + Manure	3.78	2.35 b	6.77 a
BF + Manure + Lime	3.86	3.28 a	5.57 a
		DTPA Fe	
BF	54.37	72.92	73.50 a
BF + Lime	55.81	74.53	76.18 a
BF + Manure	44.38	63.00	51.63 b
BF + Manure + Lime	40.33	52.32	48.37 b
		DTPA Ni	
BF	0.045	0.075 b	0.091
BF + Lime	0.043	0.071 b	0.108
BF + Manure	0.048	0.093 a	0.152
BF + Manure + Lime	0.042	0.097 a	0.130

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-17. Effect of lime and poultry manure on the Morgan extractable Al, pH, and % C of soil samples collected after harvest for Rangpur experiment (APR 2004), Rangpur experiment (OCT 2004), and Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	Rangpur Experiment (APR 2004)	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)
		Morgan Al	
		mg kg^{-1}	
BF	81 a†	121 a	96 a
BF + Lime	67 b	125 a	84 b
BF + Manure	34 c	60 b	34 c
BF + Manure + Lime	27 c	41 c	33 c
		pH	
BF	4.36 b	3.64 c	3.59 c
BF + Lime	4.48 b	3.57 c	3.47 c
BF + Manure	4.95 a	4.34 b	4.24 b
BF + Manure + Lime	4.95 a	4.68 a	4.51 a
		Total C	
		%	
BF	0.99	0.89	0.93
BF + Lime	1.00	0.90	0.91
BF + Manure	0.96	0.87	0.97
BF + Manure + Lime	1.08	0.99	0.98

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

from 2 to 5 %. The Ca concentration of the poultry manure used in this study ranged from 12 to 16 % (Table 2-2). Therefore, poultry manure, in this situation, has the potential to provide approximately 2900 kg Ca ha^{-1} or the equivalent of more than 10 times the amount of Ca as the lime treatment.

In the first (APR 2004) Rangpur experiment, neither the application of lime nor poultry manure affected the petiole nutrient concentration, with the exception of the Mn content of the leaves (Table 2-18 and Table 2-19). In this instance, the Mn concentration of the petioles tended to decrease with manure additions. In addition, the petiole concentration of K and Cu were below the sufficiency range (i.e., 33 to 55 g kg^{-1} for K and 4-10 mg kg^{-1} for Cu) established for papaya (Mills and Jones, 1996; Nishina et al., 2000) (Table 2-18 and Table 2-19).

For the second (OCT 2004) Rangpur experiment, the P, K, and Ca concentration of the petioles tended to increase with manure application, while the Mn and Zn concentration tended to be lower after manure application (Table 2-20 and Table 2-21). The Mg concentration tended to increase from both the lime (i.e., dolomite) and manure application (Table 2-20). For P, a concentration between 2.2 to 4.0 g kg^{-1} is recommended to obtain maximum papaya yield (Mills and Jones, 1996). For this experiment, the papaya plants were either deficient or following manure application barely sufficient in P (Table 2-20) (Mill and Jones, 1996). Similar to the first (APR 2004) experiment, the papaya plants in the second (OCT 2004) Rangpur experiment were also deficient in K irrespective of treatment (Table 2-20). The petiole concentration was slightly below the sufficiency range for Mg from leaves sampled in August 2005 and for Cu from leaves sampled in October 2005 (i.e., 4 to 12 g kg^{-1} for Mg and 4 to 10 for Cu mg kg^{-1}) (Table 2-20 and Table 2-21) (Mills and Jones, 1996).

Table 2-18. Effect of lime and poultry manure on total macronutrient concentration of petiole samples for Rangpur experiment (APR 2004) located at Rangpur OFRD, Bangladesh.

Treatment	Sampled: September 2004 ---- $g\ kg^{-1}$ ----
	N
BF	11.98†
BF + Lime	11.37
BF + Manure	11.60
BF + Manure + Lime	11.37
	P
BF	2.23
BF + Lime	2.75
BF + Manure	2.98
BF + Manure + Lime	3.01
	K
BF	20.12
BF + Lime	20.06
BF + Manure	24.06
BF + Manure + Lime	22.77
	Ca
BF	13.39
BF + Lime	12.55
BF + Manure	10.38
BF + Manure + Lime	9.82
	Mg
BF	4.29
BF + Lime	5.38
BF + Manure	5.35
BF + Manure + Lime	5.22

† Means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-19. Effect of lime and poultry manure on total micronutrient concentration of petiole samples for Rangpur experiment (APR 2004) located at Rangpur OFRD, Bangladesh.

Treatment	Sampled: September 2004
	------------------------------ $mg\ kg^{-1}$ ------------------------------
	Cu
BF	3.15†
BF + Lime	2.89
BF + Manure	2.02
BF + Manure + Lime	1.57
	Mn
BF	93.49 a
BF + Lime	86.57 ab
BF + Manure	44.38 bc
BF + Manure + Lime	36.36 c
	Zn
BF	51.46
BF + Lime	41.71
BF + Manure	21.46
BF + Manure + Lime	15.74
	Fe
BF	23.70
BF + Lime	37.66
BF + Manure	23.25
BF + Manure + Lime	20.32
	Mo
BF	0.79
BF + Lime	0.97
BF + Manure	0.79
BF + Manure + Lime	0.77

† Means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

For the third (APR 2005) Rangpur experiment, the petiole concentration of P and Ca tended to be higher and the concentration of Mn and Zn tended to be lower with manure application (Table 2-22 and Table 2-23). The petiole concentration of Mg tended to be greater when manure and/or lime were applied. The Cu concentration was inconsistent between sampling dates (e.g., September and November 2005) (Table 2-23). In addition, when manure was applied, the petiole P concentration was within the sufficiency range. If manure was not applied (i.e., treatments one and two), the plants were deficient in P. Unlike the first (APR 2004) and second (OCT 2004) Rangpur experiments, the petiole K concentration was within the sufficiency range for the November 2005 sampling date. However, like the other experiments, the K concentration was below the sufficiency range for the other sampling date (i.e., September 2005). The Mg concentration also tended to be below the sufficiency range irrespective of treatment.

Overall, petiole analysis suggested that the concentration of P, K, and Ca tended to be greater and the concentration of Mn and Zn was lower when poultry manure was applied. The petiole concentration of Mg was generally greater when either manure or lime was applied. When manure was not added, the plants tended to be deficient in P. Additionally, for all of the treatments, the plants were deficient in K.

Acid soils ($pH \leq 5.5$) can negatively impact crop growth and yield due to Al, Mn, and Fe toxicities, and possibly from nutrient deficiencies (e.g., P deficiency) (Kochian et al., 2004). In previous studies, animal manure amendments have been shown to increase soil pH and reduce Al toxicity (Naramabuye and Haynes, 2006; Tang et al., 2007). This improvement in soil conditions is most likely related to either the liming effect of animal manures or from the organic matter in the manure complexing with Al (Narambuye and Haynes, 2006; Tang et al., 2007). In addition,

Table 2-20. Effect of lime and poultry manure on total macronutrient concentration of petiole samples for Rangpur experiment (OCT 2004) located at Rangpur OFRD, Bangladesh.

Treatment	Sampled: August 2005	Sampled: October 2005
	$g\ kg^{-1}$	
	N	
BF	12.01†	10.95
BF + Lime	11.65	9.86
BF + Manure	13.30	10.75
BF + Manure + Lime	12.68	11.21
	P	
BF	1.51 b	1.60 a
BF + Lime	1.65 b	1.22 b
BF + Manure	2.10 ab	1.56 a
BF + Manure + Lime	2.33 a	1.55 a
	K	
BF	17.28 b	14.82 b
BF + Lime	13.87 b	11.77 b
BF + Manure	24.10 a	19.51 a
BF + Manure + Lime	24.14 a	20.12 a
	Ca	
BF	10.68 b	13.32
BF + Lime	11.14 b	14.67
BF + Manure	15.52 a	14.78
BF + Manure + Lime	13.49 ab	16.14
	Mg	
BF	3.90	3.26 c
BF + Lime	4.28	4.40 b
BF + Manure	3.94	4.77 ab
BF + Manure + Lime	3.83	5.46 a

† Within a sampling date, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-21. Effect of lime and poultry manure on total micronutrient concentration of petiole samples for Rangpur experiment (OCT 2004) located at Rangpur OFRD, Bangladesh.

Treatment	Sampled: August 2005	Sampled: October 2005
	------------------------------- mg kg^{-1}	-------------------------------
	Cu	
BF	3.37 b†	2.40
BF + Lime	4.19 a	1.51
BF + Manure	4.60 a	1.00
BF + Manure + Lime	4.53 a	1.47
	Mn	
BF	111.60 a	99.12 ab
BF + Lime	93.69 ab	138.01 a
BF + Manure	57.13 bc	62.13 bc
BF + Manure + Lime	54.55 c	56.20 c
	Zn	
BF	23.87 b	25.19 a
BF + Lime	32.24 a	22.12 a
BF + Manure	20.28 b	12.96 b
BF + Manure + Lime	23.21 b	15.21 b
	Fe	
BF	22.29	23.79
BF + Lime	22.47	25.46
BF + Manure	25.37	17.56
BF + Manure + Lime	19.46	19.53
	Mo	
BF	0.08	0.95
BF + Lime	0.08	0.97
BF + Manure	0.07	0.95
BF + Manure + Lime	0.06	0.80

† Within a sampling date, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-22. Effect of lime and poultry manure on total macronutrient concentration of petiole samples for Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	Sampled: September 2005	Sampled: November 2005
	g kg^{-1}	
	N	
BF	11.23†	12.60
BF + Lime	12.23	13.38
BF + Manure	12.49	14.76
BF + Manure + Lime	12.63	16.11
	P	
BF	1.80 b	1.74
BF + Lime	1.82 b	2.07
BF + Manure	2.77 a	2.85
BF + Manure + Lime	3.04 a	2.94
	K	
BF	23.41	27.73
BF + Lime	23.90	33.56
BF + Manure	26.90	39.30
BF + Manure + Lime	28.35	37.07
	Ca	
BF	13.14	13.80 b
BF + Lime	12.85	14.20 b
BF + Manure	12.94	20.81 a
BF + Manure + Lime	13.11	19.01 a
	Mg	
BF	2.44 b	2.34 c
BF + Lime	3.85 a	4.02 a
BF + Manure	2.90 b	3.25 b
BF + Manure + Lime	3.20 ab	3.65 ab

† Within a sampling date, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 2-23. Effect of lime and poultry manure on total micronutrient concentration of petiole samples for Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh.

Treatment	Sampled: September 2005	Sampled: November 2005
	------------------------------ mg kg^{-1}	------------------------------
	Cu	
BF	4.99 a†	2.89 b
BF + Lime	5.06 a	5.02 a
BF + Manure	4.09 b	4.07 ab
BF + Manure + Lime	4.30 ab	3.88 ab
	Mn	
BF	96.49 a	161.80 a
BF + Lime	56.03 b	86.15 b
BF + Manure	23.92 c	48.74 b
BF + Manure + Lime	23.41 c	54.45 b
	Zn	
BF	39.64 a	66.14 a
BF + Lime	34.01 a	38.13 b
BF + Manure	17.96 b	17.55 c
BF + Manure + Lime	17.83 b	16.76 c
	Fe	
BF	17.06	34.97
BF + Lime	18.59	31.28
BF + Manure	14.65	32.03
BF + Manure + Lime	14.84	32.05
	Mo	
BF	0.05 c	1.00 a
BF + Lime	0.05 c	0.21 b
BF + Manure	0.31 b	0.13 b
BF + Manure + Lime	0.41 a	0.30 b

† Within a sampling date, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

the liming of acid soils will usually increase the concentration of soil P (Havlin et al., 2005). In Rangpur, the application of poultry manure greatly improved yield and is probably the result of an increased soil pH, a reduced concentration of soil Al, and an improved concentration of plant P associated with manure application.

In conclusion, when manure was applied, papaya plants that were transplanted in the spring tended to have a slightly larger plant girth, plant height, and yield as compared to papaya plants that were transplanted in the fall. However, papaya that was transplanted in the fall provided ripe fruit approximately four to eight weeks earlier than papaya transplanted in the spring.

The application of lime had only a very limited effect on yield, plant nutrition, and soil properties for each experiment. Lime additions slightly improved papaya growth early in the season. Although to a lesser extent as compared to the poultry manure application, the addition of lime (i.e., dolomite) also increased the concentration of leaf and soil Mg and reduced the concentration of soil Al. In addition, lime increased soil pH only when manure was applied.

In general, the application of poultry manure increased the soil concentration of P, Ca, Mg, and Zn and the petiole concentration of P, Ca, Mg, and K. In contrast, the application of poultry manure lowered the soil concentration of Al and the petiole concentration of Mn and Zn. The majority of plants irrespective of treatment were deficient in K for every experiment. In addition, the application of manure was generally required to prevent P deficiency.

To fully understand the positive yield response to poultry manure application found in this study, further studies are needed. For example, an experiment with higher application rates of lime may explain whether this improvement in yield is the result of the manure acting as a fertilizer source, or rather its favorable effect on soil pH, or possibly a combination of both of these factors. Additional studies which evaluate varying application rates of poultry manure may further improve papaya yield. Also, because of the importance of organic amendments to papaya production in Bangladesh, future studies which evaluate the effect of other commonly used amendments (e.g., cattle manure and household waste) on soil properties and papaya yield would be beneficial.

Overall, if approximately 85% of the papaya plants in this study were female, the papaya plants that received manure in Rangpur produced approximately 42 t ha^{-1}. For the plants that did not receive manure, these plants only produced 22 t ha^{-1}. However, all of the experiments had higher yields as compared to national average of 6.6 t ha^{-1} in Bangladesh (FAOSTAT, 2005).

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CHAPTER THREE

INFLUENCE OF MICRONUTRIENT AND MANURE APPLICATION ON PAPAYA YIELD, PLANT NUTRITION, AND SOIL FERTILITY IN PABNA AND ISHURDI

Introduction

Papaya is currently being grown both commercially and in home gardens in Bangladesh and has the potential to produce fruit year round (Islam, 2003; Manshardt, 1992). The average fruit yield of papaya is extremely low (6.6 t ha^{-1}) and is most likely the result of plant disease (e.g., papaya ringspot virus), flooding, lack of varieties, and/or improper fertilizer management (FAOSTAT, 2005). In Bangladesh, approximately 69% of soils are deficient in boron (B) (Graham et al., 2007). Boron is essential for the formation and structure of cell walls and is particularly important for papaya (*Carica papaya*) fruit production (Marschner, 1995; Havlin et al., 2005). If a papaya plant is deficient in B, the surface of the papaya fruit will be misshapen and have a bumpy appearance (Nishina et al., 2000). Boron deficiency in plants is generally associated with high pH soils, sandy soils, and soils with low organic matter content (Welch et al., 1991; Havlin et al., 2005). Results from a two year study in Gazipur, Bangladesh determined that the application of both B and molybdenum (Mo) increased papaya yield (Talukder et al., 2001). However, it could not be ascertained from this study whether the improvement in yield was the result of B and/or Mo application (Talukder et al., 2001).

Zinc (Zn) deficiency has been observed in wetland rice (*Oryza sativa*) production throughout Asia (Havlin et al., 2005; Lopes, 1980). In Bangladesh, an estimated 85% of soils are deficient in Zn (Graham et al., 2007). Zinc is essential for the activity of various enzymes, synthesis of the growth hormone indoleacetic acid, and the maintenance of plant membranes (Marschner, 1995). Zinc deficiency in plants is generally found in high pH soils with reduced Zn availability or possibly in sandy, acid soils with low total Zn (Welch et al., 1991; Havlin et al., 2005). A soil with a high concentration of P may also induce Zn deficiency in plants (Welch et al., 1991; Havlin et al., 2005). In India, the application of Zn and B fertilizer improved papaya yield (Kavitha et al., 2000).

Based on a study from Pabna, Bangladesh, papaya farmers typically did not apply fertilizer or supplied only a limited amount to their land (F. Islam, unpublished data, 2003). Micronutrient fertilizers, such as borax or boric acid, were even less likely to be applied (F. Islam, unpublished data, 2003). In addition, results from a household survey in Pabna and Rangpur, Bangladesh determined that only 19% of those interviewed applied micronutrient fertilizers to their papaya plants (J. King, unpublished data, 2005). Due to widespread deficiencies of soil Zn and B in Bangladesh and the relatively low utilization of micronutrient fertilizers in papaya production, one objective of this study was to determine the effect of Zn and B fertilizer application on soil properties, plant nutrition, and papaya yield.

The utilization of organic amendments, such as animal manures, in crop production is associated with an increased amount of organic matter in the soil. A greater soil organic matter content will generally improve soil structure, water holding capacity, and water infiltration rate (Brady and Weil, 1996). In addition, animal manures may also supply both macronutrients and micronutrients to crops, decrease Al availability in soil, and potentially increase P availability in soil (Havlin et al., 2005). However, there can be substantial variability in the nutrient content of manure (Havlin et al., 2005; Wolf and Snyder, 2003). The animal's diet, bedding, and subsequent storage of the manure can all affect the nutrient content of the manure (Wolf and Snyder, 2003; Havlin et al., 2005). Although there may be some inconsistency in their composition, the application of animal manures (e.g., poultry manure) has been associated with improvements in plant growth and yield (Weil and Magdoff, 2004; Havlin et al., 2005). Therefore, the overall objective of this study was to evaluate the effect of poultry manure, Zn, and B on papaya yield, plant nutrition, and soil properties in Pabna and Ishurdi, Bangladesh.

Materials and Methods

Between fall 2004 and spring 2006, five field experiments were conducted in Pabna and Ishurdi, Bangladesh. The five experiments will be referred to as “Pabna”, “Ishurdi”, “farmer field experiment no.1”, “farmer field experiment no.2”, and “farmer field experiment no.3” in this publication. The Pabna experiment was located at the On Farm Research Division, Bangladesh Agricultural Research Institute in Pabna and the Ishurdi experiment was located on a farmer’s field in Ishurdi. Prior to these field experiments, the land on the Pabna research station had been fallow for one year and the land in Ishurdi had been used to cultivate taro (*Colocasia esculenta*) and mungbean (*Vigna radiata*). In addition, the farmer field experiment in Ishurdi was surrounded by a large area of land dedicated to papaya cultivation. For the Pabna and Ishurdi experiments, eight week old papaya seedlings were transplanted in April 2004 and April 2005, respectively. There is only one papaya variety (i.e., ‘Shahi’) in Bangladesh. Unfortunately, due to damage from disease and hail, ‘Shahi’ papaya seed is currently unavailable for cultivation (N. Islam, personal communication, 2004). Therefore, the papaya seed used for these experiments was collected instead from a large papaya grower in Ishurdi. The soil in Ishurdi was a silty clay loam (i.e., 4% sand, 56% silt, 40% clay) with a slightly acidic pH of 5.8. At the Pabna research station, the soil was a silt loam (i.e., 38% sand, 54% silt, and 8% clay) with a neutral pH of 7.2. A description of the initial soil characteristics for Pabna and Ishurdi experiments are detailed in Table 3-1.

The farmer field experiment no.1, no.2, and no.3 were all located within close proximity to each other on a farmer's field in Pabna. Before these experiments were initiated, this land had been used for tumeric (*Curcuma longa*) cultivation. For each of the three experiments, eight week old papaya seedlings were transplanted in April 2005. The papaya seed used in these experiments was collected from a large papaya grower in Rangpur, Bangladesh. The soil at this site was a silt loam (i.e., 29% sand, 62% silt, and 9% clay) with pH of 5.9 to 6.2. A description of the initial soil characteristics for the farmer field experiment no.1, no.2, and no.3 are detailed in Table 3-2.

For the Pabna experiment, the treatments were as follows: treatment one received chemical fertilizer only, treatment two received an additional 7.7 kg Zn ha^{-1} from $ZnSO_4$ and 4.7 kg B ha^{-1} from borax, treatment three received 21 t ha^{-1} poultry manure (i.e., 10 kg poultry manure $plant^{-1}$), treatment four received 21 t ha^{-1} poultry manure, 7.7 kg Zn ha^{-1}, and 4.7 kg B ha^{-1}, and treatment five received 53 t ha^{-1} poultry manure (i.e., 25 kg poultry manure $plant^{-1}$) without any additional chemical fertilizer. These treatments are referred to as base fertilizer (BF), BF + Zn,B, BF + Manure, BF + Manure + Zn, B, and Manure only. For the Ishurdi experiment the treatments were the same as Pabna experiment with the exception that the B fertilizer rate was reduced to 2.3 kg B ha^{-1}. Treatments one, two, three, and four all received 533 kg N ha^{-1}, 186 kg P ha^{-1}, 442 kg K ha^{-1}, 72 kg S ha^{-1}, each year from urea, triple super phosphate, muriate of potash, and gypsum, respectively. For both of the experiments, urea and muriate of potash were applied monthly, triple super

Table 3-1. Pre-plant soil characteristics of the Pabna and Ishurdi experiments in Bangladesh.

Property Analyzed	Pabna Experiment		Ishurdi Experiment
	-----------------------------	mg kg^{-1}	----------------------------------
Total N	514 ± 17†		1152 ± 20
Morgan P	9.8 ± 0.7		68.6 ± 3.8
Morgan K	54 ± 3.3		151 ± 4.3
Morgan Ca	16388 ± 206		3631 ± 25
Morgan Mg	431.1 ± 37.8		641.7 ± 18.7
DTPA Cu	2.26 ± 0.11		4.40 ± 0.27
DTPA Mn	7.68 ± 0.28		30.70 ± 1.90
DTPA Zn	0.41 ± 0.03		8.44 ± 0.46
DTPA Fe	20.73 ± 1.19		46.91 ± 3.77
DTPA Ni	0.09 ± 0.01		0.98 ± 0.09
Morgan Al	12.9 ± 0.8		8.5 ± 0.9
	-------------------------------	%	--------------------------------------
Total C	1.55 ± 0.05		1.00 ± 0.01
Total C (without CO_3)	0.61 ± 0.03		n/a
	--		
pH	7.23 ± 0.16		5.82 ± 0.12

† Data calculated from four replications and standard deviation, respectively.

Table 3-2. Pre-plant soil characteristics of three farmer field experiments in Pabna, Bangladesh.

Property Analyzed	Farmer Field Experiment no.1	Farmer Field Experiment no.2	Farmer Field Experiment no.3
	-------------------------------	mg kg^{-1}	-------------------------------
Total N	527 ± 53†	461 ± 84	345 ± 50‡
Morgan P	24.4 ± 1.3	21.1 ± 3.0	8.6 ± 0.6
Morgan K	79 ± 5.7	70 ± 4.4	67 ± 3.8
Morgan Ca	14464 ± 83	13397 ± 162	14820 ± 97
Morgan Mg	237.6 ± 6.5	213.8 ± 5.9	282.2 ± 4.6
DTPA Cu	1.25 ± 0.04	1.09 ± 0.12	1.10 ± 0.05
DTPA Mn	11.98 ± 0.31	10.03 ± 1.29	7.48 ± 0.29
DTPA Zn	2.02 ± 0.16	3.78 ± 1.54	0.65 ± 0.06
DTPA Fe	12.88 ± 0.88	9.87 ± 0.47	9.49 ± 0.35
DTPA Ni	0.12 ± 0.01	0.09 ± 0.02	0.07 ± 0.01
Morgan Al	19.2 ± 0.3	12.0 ± 1.0	15.4 ± 0.4
	-------------------------------	%	-------------------------------
Total C	1.30 ± 0.04	1.19 ± 0.06	1.18 ± 0.08
Total C (without CO_3)	0.55 ± 0.06	0.50 ± 0.05	0.41 ± 0.05
	-------------------------------	-------------------------------	-------------------------------
pH	6.19 ± 0.04	5.95 ± 0.06	6.13 ± 0.06

† Data calculated from four replications and standard deviation, respectively.

‡ Data calculated from three replications and standard deviation, respectively.

phosphate and poultry manure were applied every six months, and the remainder of the fertilizer was applied prior to transplanting. For the Pabna experiment, poultry manure from sample lot A was applied prior to transplanting and then again after six months. For the Ishurdi experiment, poultry manure from sample lot A was applied prior to transplanting and the second application from sample lot C was applied after six months. The nutrient concentration for each of the sample lots of manure was determined (Table 3-3).

For the farmer field experiment no.1, the treatments were as follows: treatment one received chemical fertilizer only, treatment two received an additional 21 t ha^{-1} poultry manure (i.e., 10 kg poultry manure $plant^{-1}$), treatment three received 21 t ha^{-1} poultry manure and 7.7 kg Zn ha^{-1} from $ZnSO_4$, treatment four received 21 t ha^{-1} poultry manure and 2.3 kg B ha^{-1} from borax, and treatment five received 21 t ha^{-1} poultry manure, 7.7 kg Zn ha^{-1}, and 2.3 kg B ha^{-1}. These treatments are referred to as BF, BF + Manure, BF + Manure + Zn, BF + Manure + B, and BF + Manure + Zn, B. In addition to these treatments, each plot received 533 kg N ha^{-1}, 186 kg P ha^{-1}, 442 kg K ha^{-1}, 72 kg S ha^{-1}, each year from urea, triple super phosphate, muriate of potash, and gypsum, respectively.

For the farmer field experiment no.2, the treatments were as follows: treatment one received chemical fertilizer only, treatment two received an additional 10 t ha^{-1} poultry manure (i.e., 5 kg manure $plant^{-1}$), treatment three received 21 t ha^{-1} poultry manure (i.e., 10 kg manure $plant^{-1}$), treatment four received 32 t ha^{-1} poultry manure (i.e., 15 kg manure $plant^{-1}$), and treatment five received 43 t ha^{-1} poultry manure (i.e., 20 kg manure $plant^{-1}$). These treatments are referred to as BF, BF + 5 kg manure $plant^{-1}$, BF + 10 kg manure $plant^{-1}$, BF + 15 kg manure $plant^{-1}$, and BF + 20 kg manure $plant^{-1}$. Each plot also received 533 kg N ha^{-1}, 186 kg P ha^{-1}, 442 kg K

Table 3-3. Analysis of poultry manure collected from Gazipur, Bangladesh.

Property Analyzed	Sample Lot A	Sample Lot B	Sample Lot C
		Total Element Concentration	
		$g\ kg^{-1}$	
N	9.9 ± 0.4†	11.4 ± 1.0	6.7 ± 0.8
P	13.7 ± 4.5	5.5 ± 0.9	2.7 ± 0.5
K	6.7 ± 0.8	8.7 ± 0.4	5.9 ± 0.7
Ca	160.8 ± 17.6	85.7 ± 4.0	119.0 ± 21.5
Mg	10.6 ± 0.8	11.4 ± 0.3	7.5 ± 0.3
		$mg\ kg^{-1}$	
Cu	70.0 ± 6.5	79.5 ± 4.9	74.6 ± 8.5
Mn	102.5 ± 44.9	1834.4 ± 205.3	1116.8 ± 565.6
Zn	259.7 ± 76.0	336.3 ± 57.2	217.1 ± 22.0
Fe	1227.1 ± 745.6	2289.9 ± 659.2	833.4 ± 767.4
Mo	0.26 ± 0.14	0.45 ± 0.02	0.45 ± 0.05
C:N	10.8 ± 0.5	8.7 ± 1.1	16.3 ± 1.1
		%	
C	10.7 ± 0.9	9.9 ± 0.5	10.9 ± 1.7
Dry matter	69.7 ± 1.0	55.3 ± 6.9	64.6 ± 3.7

† Data calculated from four replications and standard deviation, respectively.

ha^{-1}, 72 kg S ha^{-1}, 7.7 kg Zn ha^{-1}, and 2.3 kg B ha^{-1} from urea, triple super phosphate, muriate of potash, gypsum, zinc sulfate, and borax, respectively.

For the farmer field experiment no.3, the treatments were as follows: treatment one received 1.2 kg B ha^{-1} (i.e., 5 g borax plant^{-1}), treatment two received 2.3 kg B ha^{-1} (i.e., 10 g borax plant^{-1}), and treatment three received 3.5 kg B ha^{-1} (i.e., 15 g borax plant^{-1}). These treatments are referred to as BF + 5 g borax plant^{-1}, BF + 10 g borax plant^{-1}, and BF + 15 g borax plant^{-1}. Each plot also received 21 t ha^{-1} poultry manure, 533 kg N ha^{-1}, 186 kg P ha^{-1}, 442 kg K ha^{-1}, 72 kg S ha^{-1}, and 7.7 kg Zn ha^{-1} from urea, triple super phosphate, muriate of potash, gypsum, and zinc sulfate.

For each of the farmer field experiments, urea and muriate of potash were applied monthly, triple super phosphate and poultry manure were applied every six months, and the remainder of the fertilizer was applied prior to transplanting. Poultry manure from sample lot B was applied prior to transplanting and then manure from sample lot C was applied after six months.

For each of the five field experiments, fertilizer was placed in a round pit that had a diameter of 80 cm and a depth of 40 cm prior to planting. The fertilizer was incorporated into the soil and then the soil was formed into a mound. Three approximately eight week old seedlings were transplanted onto each mound. About two months after transplanting, excess male and hermaphrodite plants were removed to leave one plant per mound. Fertilizer that was applied after transplanting was placed in a ring around each plant at a depth of approximately 5 cm and then covered with surrounding soil.

For the Pabna, Ishurdi, farmer field no.1, and farmer field no.2 experiments, the experimental design was a randomized complete block design with four replications. The plant spacing was two meters between rows and two meters between plants in a row. Each plot consisted of nine plants for a total plot size of 36 m^2. In addition, an extra one-half meter between plots was allotted to minimize any potential border effects among plots. For farmer field no.3 experiment, the experimental design was a randomized complete block design with three replications. Each plot consisted of six plants that were spaced two meters between rows and two meters between plants in a row. The total plot size for this experiment was 24 m^2. The description and experimental design for each of these experiments are summarized in Table 3-4 and Table 3-5.

Papaya fruit was harvested at the color break stage from late October/early November 2005 to early April 2006 for the Pabna, farmer field no.1, no.2, and no.3 experiments. Unfortunately, the Pabna experiment at the research station was completely destroyed from flood damage. For this experiment only, green papaya was harvested over a two day period in mid September 2004. Plant girth for each plant was measured at a 50 cm height in September 2004 for the Pabna experiment and in September 2005 for the other experiments.

For soil analyses, soil samples were collected before transplanting and after harvest for each experiment. For the Pabna, Ishurdi, farmer field no.1 and no.2 experiments, nine cores from every plot were collected with a soil augur (4 cm in diameter and 18 cm in length) from 0 to 20 cm depth. For the farmer field experiment no.3, six cores were collected from every plot. The soil was mixed and a representative soil sample was obtained. In order to determine the soil concentration of P, K, Ca, Mg, and Al, available nutrients were extracted with Morgan's solution (i.e., sodium acetate/acetic acid solution) (Morgan, 1941). In order to determine the soil micronutrient (i.e., Cu, Mn, Zn, Fe, Ni) concentration, soil samples were extracted with the diethylenetriaminepentaacetic acid – triethanolamine (DTPA-TEA, pH 7.3) method (Lindsay and Norvell, 1978). All samples were then analyzed

Table 3-4. Description of field experiments that were conducted from 2004 to 2006 in Pabna and Ishurdi, Bangladesh.

Name:	Pabna Experiment	Ishurdi Experiment
Design:	RCB	RCB
Replications:	4	4
Plot size:	36 m^2	36 m^2
Plants $plot^{-1}$:	9	9
Transplant Date:	April 2004	April 2005
Treatments:		
1	BF	BF
2	BF + Zn, B	BF + Zn, B
3	BF + Manure	BF + Manure
4	BF + Manure + Zn, B	BF + Manure + Zn, B
5	Manure only	Manure only

Table 3-5. Description of three farmer field experiments that were conducted from 2005 to 2006 in Pabna, Bangladesh.

Name:	Farmer Field Experiment no.1	Farmer Field Experiment no.2	Farmer Field Experiment no.3
Design:	RCB	RCB	RCB
Replications:	4	4	3
Plot size:	36 m^2	36 m^2	24 m^2
Plants $plot^{-1}$:	9	9	6
Transplant Date:	April 2005	April 2005	April 2005
Treatments:			
1	BF	BF	BF + 5 g borax $plant^{-1}$
2	BF + Manure	BF + 5 kg manure $plant^{-1}$	BF + 10 g borax $plant^{-1}$
3	BF + Manure + Zn	BF + 10 kg manure $plant^{-1}$	BF + 20 g borax $plant^{-1}$
4	BF + Manure + B	BF + 15 kg manure $plant^{-1}$	
5	BF + Manure + Zn,B	BF + 20 kg manure $plant^{-1}$	

by inductively coupled plasma atomic emission spectroscopy (Spectro Ciros CCD ICP, Germany). Soil pH was determined by preparing a 2:1 deionized water: soil mixture and then analyzing the mixture using a pH electrode.

In order to determine leaf nutrient concentrations, three petiole samples under the most recently set fruit were collected per plot for the Pabna, farmer field no.1, no.2, and no.3 experiments (Nishina et al., 2000). The Ishurdi experiment was severely affected with papaya ringspot virus and only two petioles were collected per plot. The petioles were dried at 70˚C for 72 hours, the sample dry weight was recorded, and then the samples were ground using a Wiley Mill. In order to determine the nutrient concentration of the poultry manure, 4 samples were collected from a sample lot. The manure samples were dried at 60˚C for 72 hours and ground using a Wiley Mill. For both leaf petiole and manure samples, 0.5 g sample was placed in a glass tube with 3.0 mL concentrated HNO_3 solution on a digestion block overnight at room temperature. An additional 1.0 mL of HNO_3 was added and the samples were slowly heated to 100˚C over 2.5 hours. After which, an additional 2.0 mL HNO_3 was added and the samples were digested at 130˚C for approximately 20 hours. The temperature of the samples was then raised to 145˚C for approximately six hours or until the sample had completely dried. Afterwards, 2 mL of H_2O_2 was added to the sample and then dried. After drying, another 2 mL of H_2O_2 was added. After the sample had been completely dried, the tubes were removed from the digestion block. Samples were then dissolved in 10 mL 5% HNO_3 and the concentration of P, K, Ca, Mg, Cu, Mn, Zn, Fe, and Mo was determined by inductively coupled plasma atomic emission spectroscopy (Spectro Ciros CCD ICP, Germany).

The concentration of B in the soil and leaf petioles were determined for the Ishurdi, farmer field no.1, and farmer field no.3 experiments. Soil B was evaluated by using a hot water extraction method that had been modified by Dr. Julie Lauren of the Crop and Soil Sciences Department at Cornell University in Ithaca, NY (J. Lauren, personal communication, 2007). Based on the Mahler et al., (1984) and Jeffrey and McCallum (1988) procedure, 10 g soil sample and 20 mL 0.01M $CaCl_2$ were placed in a plastic centrifuge tube, boiled for 14 minutes, and then filtered (i.e., Whatman no.42). For leaf B analysis, 0.5 g plant samples were dry ashed at 500˚C for 8 hours, Afterwards, 0.25 mL 30% H_2O_2 was added and samples were dry ashed again at 450˚C for 2 hours. When cool, 0.25 mL of 6 N HCl and 25 mL 5% HNO_3 were added to the sample. Both of the solutions from the leaf and soil analyses were analyzed for B by inductively coupled plasma atomic emission spectroscopy (Spectro Ciros CCD ICP, Germany).

In order to evaluate the carbon (C) and nitrogen (N) content of the soil, petiole, and poultry manure samples, each of the samples was first ball-milled. After milling, the total C and N was determined by dry combustion using an Europa Scientific Roboprep C/N analyzer (Nelson and Sommers, 1996). In addition, the soil from the Pabna, farmer field no.1, no.2, and no.3 experiments had a substantial amount of carbonates. In order to determine the concentration of carbonates relative to the total C content, the initial soil samples were treated with 1M HCl and dried at 65˚C for four hours prior to dry combustion (Table 3-1 and Table 3-2). An analysis of variance was conducted on the data and mean separation was obtained with Duncan's New Multiple Range Test using MSTAT (Freed et al., 1993).

Results and Discussion

In Ishurdi, papaya yield was significantly lower for the Zn, B, and poultry manure application (i.e., treatment four) and also for the manure only treatment (i.e., treatment five) (Table 3-6). For this experiment, the base fertilizer treatment which only received chemical fertilizer (i.e., urea, triple super phosphate, muriate of potash, and gypsum) had the highest yield. Unfortunately, the Pabna experiment was damaged by floods and overall, the yield was lower from this experiment as compared to the Ishurdi experiment (Table 3-6). In Pabna, the plants were completely harvested in September, while in Ishurdi, the papaya plants were harvested through the following spring. For the Pabna experiment, there were not any significant differences among treatments for the amount and/or quantity of papaya produced (Table 3-7). The size of the papaya fruit ranged from 0.50 to 0.70 kg in Ishurdi and from 0.20 to 0.60 kg in Pabna (Table 3-8).

For the Ishurdi experiment, the plant girth of the papaya plants was not affected by any of the treatments (Table 3-9). However, in Pabna, the treatment which received Zn and B (i.e., treatment two) tended to be smaller (e.g., plant girth and petiole weight) as compared to plants from the other treatments (Table 3-9 and Table 3-10). In Ishurdi, even though these plants had received a high rate of poultry manure (i.e., 25 kg $plant^{-1}$), the petiole weight was statistically lower for the manure only treatment, (Table 3-10). Overall, the application of Zn, B, and poultry manure either did not impact or slightly decreased plant growth and yield for these experiments.

For the farmer field experiment no.1, the yield, plant girth, and the fresh and dry petiole weight were not affected any of the treatments (Table 3-11, Table 3-12, and Table 3-13). The quantity of fruit produced per plant was slightly affected by treatment. In this case, the plants which received poultry manure, Zn, and B (i.e., treatment five) generally produced more fruit than the plants which received only inorganic fertilizer (i.e., treatment one), inorganic fertilizer with manure (i.e. treatment two), and inorganic fertilizer with manure and Zn (i.e., treatment three) (Table 3-11).

Table 3-6. Effect of Zn, B, and poultry manure on papaya yield for Pabna and Ishurdi experiments in Bangladesh.

Treatment	Pabna Experiment	Ishurdi Experiment
	-------------------------------- kg $plant^{-1}$	----------------------------
BF	4.7†	11.0 a
BF + Zn, B	2.5	8.1 abc
BF + Manure	7.1	9.3 ab
BF + Manure + Zn, B	7.6	6.0 bc
Manure only	6.8	5.1 c

† Within an experiment, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-7. Effect of Zn, B, and poultry manure on the quantity of fruit produced for Pabna and Ishurdi experiments in Bangladesh.

Treatment	Pabna Experiment	Ishurdi Experiment
	-------------------------- no. of fruit $plant^{-1}$	------------------------
BF	9†	16
BF + Zn, B	6	12
BF + Manure	13	11
BF + Manure + Zn, B	13	10
Manure only	11	9

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-8. Effect of Zn, B, and poultry manure on mean fruit weight for Pabna and Ishurdi experiments in Bangladesh.

Treatment	Pabna Experiment	Ishurdi Experiment
	---------------------------------- kg	---------------------------------
BF	0.39†	0.65
BF + Zn, B	0.21	0.70
BF + Manure	0.60	0.70
BF + Manure + Zn, B	0.64	0.53
Manure only	0.57	0.57

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

For the farmer field no.2 experiment, the application of varying rates of manure did not affect the papaya yield, plant girth, or petiole weight (Table 3-14, Table 3-15, and Table 3-16). However, the plants which received 15 kg manure $plant^{-1}$ produced slightly more fruit as compared to the other treatments (Table 3-14). For the farmer field no.3 experiment, the application of different rates of B fertilizer did not impact papaya yield, quantity of fruit produced, plant girth, or the petiole weight (Table 3-17, Table 3-18, and Table 3-19).

In Ishurdi, the plants were heavily infected with papaya ringspot virus and at the Pabna research station, the plants were completely destroyed by flood damage. Therefore, both of these experiments were affected by factors that negatively impacted papaya yield at these locations. In contrast, papaya plants from the farmer field experiments were not affected by flooding or plant disease and with the chemical fertilizer applied had substantially higher yield. For example, the yield in Pabna ranged from 3 to 8 kg $plant^{-1}$, the yield in Ishurdi ranged from 5 to 11 kg $plant^{-1}$, and the yield for the farmer field experiments ranged from 28 to 43 kg $plant^{-1}$. Similarly, the fruit size for the Pabna experiment ranged from 0.20 to 0.60 kg, for the Ishurdi experiment ranged from 0.50 to 0.70, and for the farmer field experiments ranged from 0.90 to 1.20 kg.

For the Ishurdi experiment, the application of poultry manure tended to increase the soil concentration of P, N, Ca, Mg, and Zn (Table 3-20 and Table 3-21). In fact, the plants which only received poultry manure (i.e., treatment five) had the highest concentration of N, Ca, Mg, and Zn as compared to the other treatments. In Ishurdi, the application of manure tended to increase the soil pH and also to decrease the concentration of soil Al (Table 3-22). Manure additions also increased the amount of total C in the soil. The manure only treatment (i.e., treatment five) which received 25 kg manure $plant^{-1}$ had the greatest soil C content, followed by the

Table 3-9. Effect of Zn, B, and poultry manure on plant girth for Pabna and Ishurdi experiments in September 2004 and September 2005, respectively.

Treatment	Pabna Experiment	Ishurdi Experiment
	------------ cm ------------	
BF	16.7 a†	21.9
BF + Zn, B	14.3 b	23.3
BF + Manure	17.8 a	24.3
BF + Manure + Zn, B	17.3 a	22.6
Manure only	17.7 a	21.0

† Within an experiment, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-10. Influence of Zn, B, and poultry manure on the petiole weight for Pabna and Ishurdi experiments sampled in September 2004 and September 2005, respectively.

Treatment	Pabna Experiment		Ishurdi Experiment	
	------------ g ------------			
	Fresh wt	Dry wt	Fresh wt	Dry wt
BF	35 bc†	4 b	153 a	16
BF + Zn, B	25 c	3 b	137 a	14
BF + Manure	66 a	8 a	156 a	16
BF + Manure + Zn, B	55 ab	7 a	135 a	15
Manure only	42 bc	5 ab	96 b	10

† Within an experiment, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-11. Effect of Zn, B, and poultry manure on papaya yield, quantity of fruit produced, and mean fruit weight for farmer field experiment no.1 located in Pabna, Bangladesh.

Treatment	Yield	Quantity	Mean fruit weight
	----- kg plant^{-1} -----	--no. of fruit plant^{-1} -	---------- kg ---------
BF	42.9†	35 bc	1.20
BF + Manure	35.7	33 c	1.12
BF + Manure + Zn	36.9	34 bc	1.09
BF + Manure + B	41.5	38 ab	1.11
BF + Manure + Zn,B	41.4	40 a	1.10

† Within a column, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-12. Effect of Zn, B, and poultry manure on plant girth for farmer field experiment no.1 located in Pabna, Bangladesh.

Treatment	September 2005
	------------------------------------ cm -----------------------------------
BF	26.6†
BF + Manure	26.8
BF + Manure + Zn	27.4
BF + Manure + B	27.0
BF + Manure + Zn,B	27.7

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-13. Effect of Zn, B, and poultry manure on petiole weight for farmer field experiment no.1 sampled in September 2005.

Treatment	Fresh wt	Dry wt
	-------------------------------------- g	-----------------------------------
BF	245†	21
BF + Manure	230	20
BF + Manure + Zn	253	24
BF + Manure + B	258	23
BF + Manure + Zn,B	267	25

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-14. Effect of different rates of manure on papaya yield, quantity of fruit produced, and mean fruit weight for farmer field experiment no.2 located in Pabna, Bangladesh.

Treatment	Yield	Quantity	Mean fruit weight
	-- kg plant^{-1} --	- no. of fruit plant^{-1} -	--------- kg --------
BF	27.9†	24 c	1.14
BF + 5 kg manure plant^{-1}	31.5	30 bc	1.14
BF + 10 kg manure plant^{-1}	33.6	29 bc	1.18
BF + 15 kg manure plant^{-1}	34.6	37 a	1.00
BF + 20 kg manure plant^{-1}	33.2	33 ab	1.05

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-15. Effect of varying amounts of manure on plant girth for farmer field experiment no.2 located in Pabna, Bangladesh.

Treatment	September 2005
	-------------------------------- cm ---------------------------------
BF	25.7†
BF + 5 kg manure plant^{-1}	26.2
BF + 10 kg manure plant^{-1}	26.5
BF + 15 kg manure plant^{-1}	26.3
BF + 20 kg manure plant^{-1}	27.1

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-16. Effect of varying amounts of manure on petiole weight for farmer field experiment no.2 sampled in September 2005.

Treatment	Fresh wt	Dry wt
	------------------------------- g	------------------------------------
BF	217†	26
BF + 5 kg manure plant^{-1}	219	25
BF + 10 kg manure plant^{-1}	255	29
BF + 15 kg manure plant^{-1}	267	28
BF + 20 kg manure plant^{-1}	237	27

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-17. Effect of varying amounts of B fertilizer on papaya yield, quantity of fruit produced, and mean fruit weight for farmer field experiment no.3 located in Pabna, Bangladesh.

Treatment	Yield	Quantity	Mean fruit size
	--- kg plant^{-1} ---	- no. of fruit plant^{-1} -	---------- kg ---------
BF + 5 g borax plant^{-1}	27.6†	25	0.86
BF + 10 g borax plant^{-1}	32.2	30	1.01
BF + 20 g borax plant^{-1}	27.6	28	0.86

† Within a column, means followed by the same letter are not different at p≤0.05 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-18. Effect of different rates of B fertilizer on plant girth for farmer field experiment no.3 located in Pabna, Bangladesh.

Treatment	September 2005
	---------------------------------- cm ----------------------------------
BF + 5 g borax plant^{-1}	26.0†
BF + 10 g borax plant^{-1}	28.4
BF + 20 g borax plant^{-1}	27.8

† Within a column, means followed by the same letter are not different at p≤0.05 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-19. Effect of different rates of B fertilizer on petiole weight for farmer field experiment no.3 sampled in September 2005.

Treatment	Fresh wt	Dry wt
	----------------------------------- g	-----------------------------------
BF + 5 g borax plant^{-1}	143†	14
BF + 10 g borax plant^{-1}	184	18
BF + 20 g borax plant^{-1}	179	19

† Within a column, means followed by the same letter are not different at p≤0.05 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-20. Effect of Zn, B, and poultry manure on the macronutrient concentration of soil samples collected after harvest for Pabna and Ishurdi experiments in Bangladesh.

Treatment	Pabna Experiment	Ishurdi Experiment
	------------------------------ mg kg^{-1}	--------------------------------
	Total N	
BF	596†	1144 d
BF + Zn, B	566	1225 d
BF + Manure	611	1392 c
BF + Manure + Zn, B	639	1537 b
Manure only	563	1848 a
	Morgan P	
BF	18 c	74 c
BF + Zn, B	18 c	68 c
BF + Manure	56 b	171 ab
BF + Manure + Zn, B	56 b	207 a
Manure only	91 a	164 b
	Morgan K	
BF	43 bc	155
BF + Zn, B	37 d	179
BF + Manure	55 a	172
BF + Manure + Zn, B	47 b	206
Manure only	41 cd	178
	Morgan Ca	
BF	16269	4041 cd
BF + Zn, B	16139	3497 d
BF + Manure	15597	4900 b
BF + Manure + Zn, B	16225	4566 bc
Manure only	15768	6445 a
	Morgan Mg	
BF	475	581 d
BF + Zn, B	501	598 cd
BF + Manure	510	674 bc
BF + Manure + Zn, B	523	695 b
Manure only	539	927 a

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-21. Effect of Zn, B, and poultry manure on the micronutrient concentration of soil samples collected after harvest for Pabna and Ishurdi experiments in Bangladesh.

Treatment	Pabna Experiment	Ishurdi Experiment
	------------------------------ mg kg^{-1}	--------------------------------
	DTPA Cu	
BF	2.27†	3.91
BF + Zn, B	2.17	4.12
BF + Manure	2.31	3.82
BF + Manure + Zn, B	2.21	4.00
Manure only	2.19	4.26
	DTPA Mn	
BF	9.24	28.50
BF + Zn, B	8.86	35.03
BF + Manure	9.82	19.64
BF + Manure + Zn, B	9.53	26.06
Manure only	8.96	18.79
	DTPA Zn	
BF	0.56 c	6.61 c
BF + Zn, B	0.84 bc	7.68 bc
BF + Manure	1.43 a	7.45 bc
BF + Manure + Zn, B	1.45 a	8.48 b
Manure only	1.26 ab	10.74 a
	DTPA Fe	
BF	28.38	48.24
BF + Zn, B	24.83	53.48
BF + Manure	30.96	41.98
BF + Manure + Zn, B	28.19	43.18
Manure only	28.57	31.32
	DTPA Ni	
BF	0.091	0.934
BF + Zn, B	0.078	1.121
BF + Manure	0.102	0.731
BF + Manure + Zn, B	0.096	0.944
Manure only	0.102	0.596

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

manure with chemical fertilizer treatments (i.e., treatments three and four), and lastly the plots which did not receive manure had the lowest percent soil C (i.e., treatments one and two) (Table 3-22). Zinc addition increased extractable Zn, but the addition of B did not increase extractable B. The concentration of B in the soil was increased for the manure only treatment (i.e., treatment five) (Table 3-23).

In Pabna, the application of poultry manure increased the concentration of P and Zn in the soil (Table 3-20). For example, treatment five (i.e., 25 kg manure $plant^{-1}$) had the highest concentration of P as compared to the other treatments. The plants which received 10 kg manure $plant^{-1}$ also had a greater soil P concentration as compared to plants that did not receive poultry manure (Table 3-20). The soil Zn content was greater from the application of Zn fertilizer (i.e., treatment two). However, the application of Zn fertilizer did not significantly alter extractable Zn when manure was also added. Otherwise, most of the nutrients analyzed were unaffected by any of the treatments in Pabna (Table 3-20, Table 3-21, and Table 3-22).

Even though the application of poultry manure positively affected the soil nutrient concentration in Pabna and Ishurdi, the damage caused by flooding and the papaya ringspot virus at these locations most likely had a much larger effect on papaya growth and yield as compared to the treatment effect.

In Ishurdi, according to petiole nutrient analysis, the plants were generally deficient in K, Mg, Cu, Zn, and Fe across all treatments (Mills and Jones, 1996; Nishina et al., 2000) (Table 3-24 and Table 3-25). For this experiment, the application of manure tended to increase the concentration of P in the leaf petiole (Table 3-24). In addition, when manure was applied at 25 kg manure $plant^{-1}$, the concentration of Mo was significantly greater as compared to the rest of the treatments (Table 3-25). In Pabna, the plants were deficient in K and Mn for all

Table 3-22. Influence of Zn, B, and poultry manure on the Morgan extractable Al, pH, and % C of soil samples collected after harvest for Pabna and Ishurdi experiments in Bangladesh.

Treatment	Pabna Experiment	Ishurdi Experiment
	Morgan Al	
	mg kg^{-1}	
BF	12.7†	9.4 a
BF + Zn, B	12.9	8.6 a
BF + Manure	10.7	8.3 a
BF + Manure + Zn, B	11.7	5.5 b
Manure only	10.8	4.7 b
	pH	
BF	7.29 a	5.78 d
BF + Zn, B	6.53 c	5.83 d
BF + Manure	6.67 c	5.97 c
BF + Manure + Zn, B	7.02 b	6.09 b
Manure only	7.39 a	6.20 a
	Total C	
	%	
BF	1.62	0.94 c
BF + Zn, B	1.60	0.91 c
BF + Manure	1.64	1.24 b
BF + Manure + Zn, B	1.70	1.35 b
Manure only	1.67	1.94 a

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-23. Effect of Zn, B, and poultry manure on hot water extractable B from soil samples and total B in petiole samples collected after harvest for the Ishurdi experiment in Bangladesh.

Treatment	Soil B concentration	Petiole B concentration
	mg kg^{-1}	
BF	1.05 b †	24.83
BF + Zn, B	1.10 b	25.49
BF + Manure	1.11 b	24.95
BF + Manure + Zn, B	1.17 b	25.12
Manure only	1.40 a	25.30

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-24. Influence of Zn, B, and poultry manure on total macronutrient concentration of petiole samples in September 2004 and 2005 for Pabna and Ishurdi experiments, respectively.

Treatment	Pabna Experiment	Ishurdi Experiment
	---------- $g\ kg^{-1}$ ----------	
	N	
BF	12.55 a†	12.33
BF + Zn, B	12.91 a	11.91
BF + Manure	11.57 a	11.19
BF + Manure + Zn, B	12.96 a	13.18
Manure only	9.23 b	10.81
	P	
BF	2.33 bc	3.14 bc
BF + Zn, B	1.87 c	3.29 bc
BF + Manure	3.94 a	2.95 c
BF + Manure + Zn, B	3.35 abc	3.68 b
Manure only	3.73 ab	4.70 a
	K	
BF	23.16 a	27.39
BF + Zn, B	23.41 a	29.51
BF + Manure	19.52 a	26.40
BF + Manure + Zn, B	19.81 a	29.14
Manure only	11.23 b	31.34
	Ca	
BF	16.31 a	13.93
BF + Zn, B	12.33 b	14.93
BF + Manure	10.99 b	14.86
BF + Manure + Zn, B	12.57 b	16.05
Manure only	11.29 b	16.44
	Mg	
BF	6.35	3.65
BF + Zn, B	5.04	3.52
BF + Manure	4.52	3.90
BF + Manure + Zn, B	6.15	3.50
Manure only	6.87	3.65

† Within an experiment, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-25. Influence of Zn, B, and poultry manure on total micronutrient concentration of petiole samples in September 2004 and 2005 for Pabna and Ishurdi experiments, respectively.

Treatment	Pabna Experiment	Ishurdi Experiment
	------------------------------- mg kg^{-1}	------------------------------
	Cu	
BF	6.88 a†	3.56
BF + Zn, B	7.02 a	3.57
BF + Manure	5.71 ab	3.26
BF + Manure + Zn, B	4.09 bc	3.70
Manure only	3.20 c	3.74
	Mn	
BF	16.42	24.07
BF + Zn, B	11.73	24.88
BF + Manure	11.63	21.48
BF + Manure + Zn, B	9.83	22.86
Manure only	11.66	21.15
	Zn	
BF	15.39	10.82
BF + Zn, B	13.48	10.54
BF + Manure	23.85	11.26
BF + Manure + Zn, B	9.31	13.36
Manure only	8.64	12.08
	Fe	
BF	37.08	19.78
BF + Zn, B	23.31	16.61
BF + Manure	27.70	20.21
BF + Manure + Zn, B	18.85	26.31
Manure only	18.12	18.84
	Mo	
BF	0.31	0.22 b
BF + Zn, B	0.28	0.22 b
BF + Manure	0.20	0.37 b
BF + Manure + Zn, B	0.23	0.34 b
Manure only	0.31	1.02 a

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

treatments (Table 3-24 and Table 3-25). The concentration of Zn and Fe in the petioles was also below the sufficiency range for papaya for treatments two, four, and five (Mills and Jones, 1996; Nishina et al., 2000). In addition, the petiole concentration of N, K, and Cu was significantly lower for plants that received 25 kg manure $plant^{-1}$ (i.e., treatment five). The application of poultry manure tended to increase the concentration of P and decrease the concentration of Ca in the leaves (Table 3-24).

For the farmer field no.1 experiment, the application of poultry manure generally increased the concentrations of P, Mg, Zn, and Fe extractable from soil (Table 3-26 and Table 3-27). The application of Zn fertilizer (i.e., treatments three and five) also increased the concentration of extractable Zn. Poultry manure also increased the soil pH and decreased the concentration of extractable Al (Table 3-28). Extractable B in the soil was also greater from manure and fertilizer application (Table 3-29). In terms of leaf nutrient concentrations, most of the nutrients analyzed were within the sufficiency range for papaya, except for Mg, Mn, and Fe which tended to be below the sufficiency range (Table 3-29, Table 3-30, and Table 3-31).

In farmer field no.2 experiment, as the application rate of manure increased, the levels of P, Mg, Cu, and Fe extractable from soil also increased (Table 3-32 and Table 3-33). Similarly, the soil pH and total C content of the soil also increased with manure application. Extractable Al also tended to be lower when manure was added (Table 3-34). In this experiment, plants were deficient in K, Mg, Mn, and Zn across all treatments (Table 3-35 and Table 3-36). Plants were also deficient in P when less than 10 kg manure was applied per plant (Table 3-35).

In farmer field experiment no.3, most of the soil nutrients and other soil properties (e.g., soil pH and total C) were not affected by the treatments (Table 3-37,

Table 3-26. Effect of Zn, B, and poultry manure on macronutrient concentration of soil samples collected after harvest for farmer field experiment no.1 located in Pabna, Bangladesh.

Treatment	Total N	Morgan P	Morgan K	Morgan Ca	Morgan Mg
	mg kg^{-1}				
BF	575†	25 b	109	14730	250 b
BF + Manure	624	86 a	124	14222	297 a
BF + Manure + Zn	650	103 a	99	14078	300 a
BF + Manure + B	749	98 a	105	14811	320 a
BF + Manure + Zn,B	729	101 a	107	14403	319 a

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-27. Effect of Zn, B, and poultry manure on micronutrient concentration of soil samples collected after harvest for farmer field experiment no.1 located in Pabna, Bangladesh.

Treatment	DTPA Cu	DTPA Mn	DTPA Zn	DTPA Fe	DTPA Ni
	mg kg^{-1}				
BF	1.32†	13.90	2.51 c	14.80 b	0.132
BF + Manure	1.47	14.37	3.83 ab	17.85 a	0.152
BF + Manure + Zn	1.41	12.61	4.58 ab	16.61 ab	0.138
BF + Manure + B	1.46	13.32	3.55 b	17.31 a	0.152
BF + Manure + Zn,B	1.49	13.67	4.76 a	17.47 a	0.156

† Within a column, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-28. Effect of Zn, B, and poultry manure on the Morgan extractable Al, pH, and % C of soil samples collected after harvest for farmer field experiment no.1 located in Pabna, Bangladesh.

Treatment	Morgan Al	pH	Total C
	mg kg^{-1}		%
BF	20.2 a†	5.78 c	1.269
BF + Manure	16.2 b	5.88 bc	1.317
BF + Manure + Zn	16.8 b	6.06 a	1.354
BF + Manure + B	16.9 b	5.97 ab	1.418
BF + Manure + Zn,B	16.5 b	5.99 ab	1.420

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-29. Influence of Zn, B, and poultry manure on the hot water extractable B from soil samples and total B in petiole samples collected after harvest for farmer field experiment no.1 located in Pabna, Bangladesh.

Treatment	Soil B concentration	Petiole B concentration
	---------- mg kg^{-1} ----------	
BF	0.18 c†	26.84
BF + Manure	0.22 bc	25.79
BF + Manure + Zn	0.26 ab	26.37
BF + Manure + B	0.27 ab	28.56
BF + Manure + Zn,B	0.28 a	25.89

† Within a column, means followed by the same letter are not different at p≤0.05 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-30. Influence of Zn, B, and poultry manure on total macronutrient concentration of petiole samples for farmer field experiment no.1 sampled in September 2005.

Treatment	N	P	K	Ca	Mg
			---------- g kg^{-1} ----------		
BF	12.70 ab†	2.61	35.67	13.93	3.36 a
BF + Manure	13.26 a	2.85	35.58	12.66	2.82 b
BF + Manure + Zn	12.09 b	2.50	33.81	12.07	2.78 b
BF + Manure + B	11.67 b	2.78	35.49	11.99	2.95 b
BF + Manure + Zn,B	11.73 b	2.28	32.65	13.48	3.03 ab

† Within a column, means followed by the same letter are not different at p≤0.05 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-31. Influence of Zn, B, and poultry manure on total micronutrient concentration of petiole samples for farmer field experiment no.1 sampled in September 2005.

Treatment	Cu	Mn	Zn	Fe	Mo
			---------- mg kg^{-1} ----------		
BF	4.84†	19.17 ab	16.57	23.99	0.123
BF + Manure	4.96	19.93 a	13.48	32.42	0.210
BF + Manure + Zn	4.40	16.76 c	14.39	16.46	0.313
BF + Manure + B	4.61	17.19 bc	15.72	18.99	0.317
BF + Manure + Zn,B	4.82	19.23 ab	16.35	22.04	0.349

† Within a column, means followed by the same letter are not different at p≤0.10 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-32. Effect of varying amounts of manure on macronutrient concentration of soil samples collected after harvest for farmer field experiment no.2 located in Pabna, Bangladesh.

Treatment	Total N	Morgan P	Morgan K	Morgan Ca	Morgan Mg
	--------------------------------		mg kg^{-1}		-----------------------------
BF	548†	26 b	74	14123	229 b
BF + 5 kg manure $plant^{-1}$	526	59 ab	69	14013	261 ab
BF + 10 kg manure $plant^{-1}$	507	58 ab	69	13675	254 ab
BF + 15 kg manure $plant^{-1}$	540	93 a	67	13598	287 a
BF + 20 kg manure $plant^{-1}$	583	76 a	68	13852	284 a

† Within a column, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-33. Effect of different rates of manure on micronutrient concentration of soil samples collected after harvest for farmer field experiment no.2 located in Pabna, Bangladesh.

Treatment	DTPA Cu	DTPA Mn	DTPA Zn	DTPA Fe	DTPA Ni
	--------------------------------		mg kg^{-1}		-----------------------------
BF	1.04 c†	10.92	2.90	10.49 c	0.091
BF + 5 kg manure $plant^{-1}$	1.04 c	10.12	4.07	11.14 bc	0.105
BF + 10 kg manure $plant^{-1}$	1.06 bc	10.59	4.07	11.52 abc	0.101
BF + 15 kg manure $plant^{-1}$	1.19 ab	10.90	3.70	12.87 ab	0.106
BF + 20 kg manure $plant^{-1}$	1.25 a	11.50	3.55	13.39 a	0.109

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-34. Effect of different rates of manure on the Morgan extractable Al, pH, and % C of soil samples collected after harvest for farmer field experiment no.2 located in Pabna, Bangladesh.

Treatment	Morgan Al	pH	Total C
	----- $mg\ kg^{-1}$ ----	------------------------	--------- % ---------
BF	14.4 a†	6.07 c	1.199 c
BF + 5 kg manure $plant^{-1}$	12.5 ab	6.43 b	1.204 bc
BF + 10 kg manure $plant^{-1}$	13.2 ab	6.62 a	1.213 bc
BF + 15 kg manure $plant^{-1}$	11.6 b	6.49 b	1.276 ab
BF + 20 kg manure $plant^{-1}$	11.3 b	6.71 a	1.301 a

† Within a column, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-35. Influence of varying amounts of manure on total macronutrient concentration of petiole samples for farmer field experiment no.2 sampled in September 2005.

Treatment	N	P	K	Ca	Mg
	------------------------------		$g\ kg^{-1}$		--------------------------------
BF	9.99†	1.88 c	29.95	12.79	2.58
BF + 5 kg manure $plant^{-1}$	9.51	2.01 bc	30.72	14.67	3.10
BF + 10 kg manure $plant^{-1}$	9.64	2.31 abc	28.41	12.31	2.81
BF + 15 kg manure $plant^{-1}$	9.89	2.55 a	31.23	13.73	2.93
BF + 20 kg manure $plant^{-1}$	9.71	2.36 ab	28.11	13.57	3.03

† Within a column, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-36. Influence of varying amounts of manure on total micronutrient concentration of petiole samples for farmer field experiment no.2 sampled in September 2005.

Treatment	Cu	Mn	Zn	Fe	Mo
	------------------------------		$mg\ kg^{-1}$		------------------------------
BF	4.20†	15.58 b	11.20	13.59	0.103 ab
BF + 5 kg manure $plant^{-1}$	4.46	19.52 a	11.55	16.84	0.059 b
BF + 10 kg manure $plant^{-1}$	4.08	15.74 b	10.62	12.67	0.064 b
BF + 15 kg manure $plant^{-1}$	4.65	16.90 b	10.60	19.26	0.095 b
BF + 20 kg manure $plant^{-1}$	3.81	16.70 b	9.18	12.90	0.209 a

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-37. Effect of varying amounts of B fertilizer on the macronutrient concentration of soil samples collected after harvest for farmer field experiment no.3 located in Pabna, Bangladesh.

Treatment	Total N	Morgan P	Morgan K	Morgan Ca	Morgan Mg
	----------------------------		mg kg^{-1}	----------------------------------	
BF + 5 g borax $plant^{-1}$	516 ab†	56	60 b	14254	298
BF + 10 g borax $plant^{-1}$	456 b	54	60 b	13264	250
BF + 20 g borax $plant^{-1}$	573 a	50	76 a	14428	300

† Within a column, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-38. Effect of varying amounts of B fertilizer on micronutrient concentration of soil samples collected after harvest for farmer field experiment no.3 located in Pabna, Bangladesh.

Treatment	DTPA Cu	DTPA Mn	DTPA Zn	DTPA Fe	DTPA Ni
	-----------------------------		mg kg^{-1}	---------------------------------	
BF + 5 g borax $plant^{-1}$	1.23†	10.22	2.86	13.07	0.105
BF + 10 g borax $plant^{-1}$	1.05	9.32	22.82	11.05	0.098
BF + 20 g borax $plant^{-1}$	1.25	10.06	2.98	12.28	0.107

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-39. Effect of different rates of B fertilizer on the Morgan extractable Al, pH, and % C of soil samples collected after harvest for farmer field experiment no.3 located in Pabna, Bangladesh.

Treatment	Morgan Al	pH	Total C
	---- mg kg^{-1} -----	------------------------	--------- % ----------
BF + 5 g borax $plant^{-1}$	13.6†	6.17	1.253
BF + 10 g borax $plant^{-1}$	12.8	6.19	1.202
BF + 20 g borax $plant^{-1}$	13.9	6.44	1.245

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-40. Influence of varying amounts of B fertilizer on the hot water extractable B from soil samples and total B in petiole samples collected after harvest for farmer field experiment no.3 located in Pabna, Bangladesh.

Treatment	Soil B concentration	Petiole B concentration
	mg kg^{-1}	
BF + 5 g borax plant^{-1}	0.28†	24.15
BF + 10 g borax plant^{-1}	0.27	24.98
BF + 20 g borax plant^{-1}	0.24	21.89

† Within a column, means followed by the same letter are not different at p≤0.05 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-41. Influence of varying amounts of B fertilizer on total macronutrient concentration of petiole samples for farmer field experiment no.3 sampled in September 2005.

Treatment	N	P	K	Ca	Mg
	g kg^{-1}				
BF + 5 g borax plant^{-1}	12.92†	3.15	32.76	13.26	2.92
BF + 10 g borax plant^{-1}	9.59	2.71	30.64	11.48	2.73
BF + 20 g borax plant^{-1}	10.92	2.42	32.12	10.94	2.52

† Within a column, means followed by the same letter are not different at p≤0.05 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-42. Influence of different rates of B fertilizer on total micronutrient concentration of petiole samples for farmer field experiment no.3 sampled in September 2005.

Treatment	Cu	Mn	Zn	Fe	Mo
	mg kg^{-1}				
BF + 5 g borax plant^{-1}	3.17†	18.45	12.56 a	12.21	0.092
BF + 10 g borax plant^{-1}	3.28	14.00	7.89 b	9.97	0.194
BF + 20 g borax plant^{-1}	3.28	15.73	12.98 a	9.58	0.186

† Within a column, means followed by the same letter are not different at p≤0.10 according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 3-38, and Table 3-39). The petiole concentration of B was not affected by any treatment and was also within the sufficiency range for papaya (Table 3-40). Otherwise, the plant concentration of K, Mg, Cu, Mn, Zn, and Fe was below the sufficiency range for these plants regardless of treatment (Table 3-41 and Table 3-42).

In conclusion, the application of poultry manure tended to have a beneficial impact on soil fertility for each of these experiments. However, the application of poultry manure, Zn, and/or B had a very limited effect on crop yield. For the Pabna experiments on farmer fields, the inorganic fertilizer regime was generally adequate to maximize papaya yield at that location. Due to the damage to the Ishurdi experiment and the Pabna research station experiment, the papaya yield was much lower as compared to the other experiments. For example, the papaya yield from the Ishurdi experiment ranged from 5 to 14 t ha^{-1} and the yield from the Pabna research station experiment ranged from 9 to 20 t ha^{-1}. However, the yield from the farmer field experiments ranged from 50 to 78 t ha^{-1}. Even though two of the five field experiments were damaged by extraneous factors, the yield of all of the experiments was generally greater than the average yield of papaya in Bangladesh (FAOSTAT, 2005).

In Bangladesh, inorganic or chemical fertilizers are expensive and may be unaffordable for many resource poor farmers, therefore additional studies which determine the effect of poultry manure without added inorganic fertilizer would be beneficial. Also, because of the widespread use of organic amendments in papaya production, further studies which evaluated other kinds of organic fertilizers (e.g., cattle manure, household waste) are needed.

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CHAPTER FOUR

IMPACT OF NUTRIENT MANAGEMENT ON PAPAYA YIELD, VITAMIN CONTENT, AND QUALITY AT TWO DIFFERENT LOCATIONS IN BANGLADESH

Introduction

Globally, an estimated three billion individuals suffer from micronutrient malnutrition (e.g., vitamin A, iodine (I), iron (Fe), and zinc (Zn) deficiencies) (Welch and Graham, 2004). These deficiencies have been associated with a higher incidence of mortality and morbidity, an increased risk of infection, reduced productivity, and impaired cognitive development and function in susceptible individuals (Welch, 2002). Numerous strategies, such as food fortification, supplementation, disease control, and various food-based approaches, are currently being utilized to minimize the negative health consequences of these deficiencies. Vitamin A deficiency, in particular, affects approximately 127 million preschool aged children and 7 million pregnant women (West, 2002). In addition, another 13 million pregnant women are considered to have low vitamin A status. Of these individuals, approximately 45% live in south and southeast Asia (West, 2002).

In Bangladesh, an estimated 30% of the children under 5 years old or 4.7 million children are deficient in vitamin A. In addition, roughly 6% and 23% of pregnant women are deficient in vitamin A or have a low vitamin A status, respectively (West, 2002). Even though there are still an estimated 94,000 cases of xerophthalmia (i.e., an ocular disorder associated with clinical vitamin A deficiency), the prevalence of this disorder has steadily declined among preschool aged children in Bangladesh over the last two decades. This improvement is most likely the result of a national vitamin A supplementation program targeted at pre-school aged children (West, 2002; Ahmed, 1999; FAO, 1999). However, additional approaches are needed to address vitamin A deficiency in children that may not have received supplementation and other at-risk individuals in this population.

Vitamin A (e.g., retinol) is a fat-soluble vitamin found in such animal foods as liver, meat, eggs, and dairy products. It is important for ocular health, immune function, and the differentiation of epithelial cells (FAO, 1999). A deficiency in vitamin A can lead to blindness and is the principal cause of blindness in preschool aged children in developing countries (Latham, 1997; West, 2002). It is associated with a higher incidence of both morbidity and mortality, and a greater susceptibility to infection (Latham, 1997). Vitamin A deficient individuals that also suffer from Fe deficiency anemia are likely to see an improvement in their Fe status after supplementation with vitamin A (Combs, 1998). In addition, a deficiency of Zn and/or protein can negatively impact vitamin A nutritional status (Combs, 1998; Latham, 1997).

Unfortunately, many of the foods that are the best sources of vitamin A (e.g., liver, eggs, and dairy products) are unaffordable for most of the population in developing countries. Under these circumstances, individuals with limited resources are more likely to obtain the majority of the vitamin A in their diet from plant food sources (i.e., provitamin A carotenoids) (de Pee and West, 1996; Welch and Graham, 1999).

Carotenoids are found in both plants and animals. In plants, they are found in such foods as green, yellow, and orange-colored fruits and vegetables (Crawley, 1993). In animals, carotenoids are found in such tissues as liver and egg yolks (Solomons and Bulux, 1997). Out of the more than 500 existing carotenoids in plants, less than 10% can be converted to vitamin A in the body (i.e., have provitamin A activity) (Welch, 1997). Provitamin A carotenoids include such compounds as β-carotene, α-carotene, and β-cryptoxanthin, while carotenoids such as lycopene, lutein, and zeaxanthin do not exhibit vitamin A activity.

The bioavailability of provitamin A carotenoids from the diet is affected by several factors including: the type of the carotenoid, the total amount of carotenoid ingested, the food matrix, and the nutritional and health status of the individual (de Pee and West, 1996; Ncube et al., 2001). For example, individuals with sufficient stores of vitamin A will convert less provitamin A carotenoids to retinol (de Pee and West, 1996). In contrast, parasitic infections may negatively affect carotenoid absorption (de Pee and West, 1996). The presence of enhancers or inhibitors in the diet may also affect carotenoid availability. For example, a diet with adequate fat will increase carotenoid bioavailability from such foods as fruits and vegetables (de Pee and West, 1996).

In plants, carotenoids function in light collection and in photoprotection during photosynthesis (Van den Berg et al., 2000). They are responsible for the vibrant pigmentation found in many fruits and flowers and therefore, are important for seed dispersal and pollination (Van den Berg et al., 2000). In addition, carotenoids also function as the precursor of the plant hormone, abscisic acid (Cunningham and Gantt, 1998).

Vitamin C or ascorbic acid serves as an antioxidant, plays a role in wound healing, and is important for the synthesis of collagen (Latham, 1997; Combs, 1998). In addition, several studies have determined that the consumption of fruits and vegetables that are high in carotenoids and ascorbic acid are inversely correlated with the incidence of cardiovascular disease and cancer. This association is believed to be mainly related to their antioxidant properties (Combs, 1998; Byers and Perry, 1992).

Vitamin C may also enhance the bioavailability of Fe from food and thus may improve Fe status in deficient individuals. In Bangladesh, data gathered from a survey conducted by Helen Keller International and the Institute of Public Health Nutrition determined that approximately 45% of preschool aged children and women of reproductive age are deficient in Fe (FAO, 1999). Therefore, an increase in consumption of vitamin C rich fruits and vegetables has the potential to reduce Fe deficiency in Bangladesh.

In plants, ascorbic acid functions as an antioxidant, enzymatic cofactor, and in electron transport (Smirnoff, 1996). In addition, for certain plant species, it is important for the formation of oxalate and tartrate (Smirnoff, 1996).

In Bangladesh, even though the availability and production of cereals has increased over the last few decades, the availability of fruits and vegetables has steadily declined from approximately 40 kg per person to 23 kg per person annually (FAO, 1999; Kiess et al., 2001). Both of these values are well below the recommended intake of at least 73 kg of fruits and vegetables per year (Welch and Graham, 1999). Besides the overall shortage of fruits and vegetables, many of the fruits and vegetables are only available during certain times of the year in Bangladesh. For example, popular fruits such as lychee (*Litchi chinensis*), mango (*Mangifera indica*), and jackfruit (*Artocarpus heterophyllus*) are only available between May and June (Monayem-Miah and Sabur, 1998). In addition, acute human malnutrition also tends to vary seasonally throughout the year in Bangladesh. For example, the prevalence of micronutrient malnutrition tends to be highest between June and August and lowest during the winter months. In the winter, the summer rice (*Oryza sativa*) has been harvested and vegetables are more readily available in the market (FAO, 1999). Therefore, this lack of availability of vitamin-rich fruits and vegetables is most likely contributing to micronutrient malnutrition in Bangladesh.

In addition to such nutritional interventions as food fortification, supplementation, and disease control, food based approaches (e.g., plant breeding and genetic engineering, fertilizer management, and crop diversification) have the potential to reduce micronutrient malnutrition in developing countries (Graham et al., 2007). For example, it is possible to select certain crops for cultivation or breeding purposes that have a high concentration of provitamin A carotenoids. Even within crop varieties, there can be substantial variation in vitamin content. In sweet potato (*Ipomoea fastigiata*), the carotenoid content varied between 0.1 and 16 mg 100 g^{-1} (Crawley, 1993). In Kenya, the total carotenoid content of papaya (*Carica papaya*) ranged from 0.8 to 3.0 mg 100 g^{-1} among cultivars (Imungi and Wabule, 1990). Also, the β-carotene content in cassava (*Manihot esculenta*) ranged from 0.1 to 2.4 mg 100 g^{-1} (Welch and Graham, 2004). Besides variation in carotenoid content, different crop cultivars may contain varying amounts of ascorbic acid. For example, the ascorbic acid content of 12 cultivars of pepper (*Capsicum annuum*) ranged from 49 to 168 mg 100 g^{-1} (Lee et al., 1995).

In order to increase the nutrient content of a crop for human consumption, one strategy is to apply the essential nutrient directly to the crop. For example, studies on wheat (*Triticum aestivum*) have shown that the soil and/or foliar application of Zn fertilizer increased Zn content in the grain (Duxbury and Welch, 1999; Graham et al., 2007). This approach has the potential to increase dietary Zn intake. Additionally, a higher concentration of Zn in the seed improved seedling growth when cultivated on Zn deficient soils (Graham et al., 2007). Unlike in this situation, an improvement in the vitamin content of crops does not result in any agricultural benefit to the plant (Bouis, 1999).

Vitamin concentration in plants may be affected by such things as: climate, light intensity, agricultural management practices, soil conditions, and crop maturity (Salunkhe and Desai, 1988). Generally, plants that have sufficient fertilization are better able to synthesize vitamins than plants cultivated under nutrient deficient soil conditions (Welch, 1998). For example, when citrus trees (*Citrus sinensis*) that were deficient in Zn, magnesium (Mg), manganese (Mn), and copper (Cu) were provided these fertilizers, the ascorbic acid concentration of the oranges was increased. However, there was not any additional benefit to applying elevated levels of these micronutrients beyond what was needed for plant growth (Nagy and Wardowski, 1988).

Carotenoid content in crops tends to be affected by the plant part, crop maturity, and nitrogen (N) supply (Welch, 2002; Crawley, 1993; Salunkhe and Desai, 1988). It has been shown that the outer leaves of cabbage (*Brassica oleracea*) tend to have a greater carotenoid content as compared to the inner leaves (Crawley, 1993). The β-carotene content of the outer leaves of the 'Savoy' cabbage, for example, is an estimated 200 times greater than the inner leaves (Van den Berg et al., 2000). Also, carotenoid content tends to be influenced by fruit maturation and ripening (Welch, 1997; Crawley, 1993). β-carotene, α-carotene, and β-cryptoxanthin all increased in several different types of pepper (e.g., bell pepper, Tabasco pepper, and habanero pepper) (*Capsicum* sp.) as the plant reached maturity (Howard et al., 2000). For example, immature peppers, on average, provided 1 to 4% of the RDA (i.e., adult males) and mature peppers provided 10 to 34% of the RDA for vitamin A (Howard et al., 2000). A similar relationship was found for such plants as mango, orange, papaya, and tomato (*Lycopersicon esculentum*) (Van den Berg et al., 2000). The carotenoid content of crops also tends to increase with N supply. For example, the β-carotene concentration of carrot (*Daucus carota*) was generally greater with increasing application rates of green manure (i.e., winter rye (*Secale cereale*) and hairy vetch (*Vicia villosa*)) (Kaack et al., 2002). In this study, the higher rates of green manure supplied a greater amount of N. However, any contribution by other plant nutrients from the green manure was not determined.

In a study conducted in Brazil, the β-Carotene, β-Cryptoxanthin and lycopene content of 'Formosa' papaya was greater in Bahia which has a warmer climate as compared to 'Formosa' papaya collected from Sao Paulo which has a cooler climate (Kimura et al., 1991). However, Kimura et al. (1991) did not mention whether there were any other differences (e.g., soil type, fertilizer management, light intensity, etc.) between these two locations.

The vitamin C content of plants generally tends to be greater under high light intensity, low temperatures, and adequate potassium (K) supply (Dumas et al., 2003; Welch, 2002; Goldman et al., 1999; Weston and Barth, 1997; Salunkhe and Desai, 1988; Nagy and Wardowski, 1988). In an experiment with oranges, fruit that was located on the outside of the tree with access to more light had higher ascorbic acid concentrations (i.e., 35 to 53 mg 100 mL^{-1} juice) as compared to fruits within the tree canopy (i.e., 30 to 41 mg 100 mL^{-1} juice) (Nagy and Wardowski, 1988). Also, tomatoes that were cultivated outside had higher vitamin C concentrations as compared to tomatoes grown in a greenhouse (Dumas et al., 2003).

Temperature may also affect the vitamin C content in crops. Guava (*Psidium guajava*) that was cultivated in the winter had higher ascorbic acid content as compared to guava that was cultivated in the spring or summer (Nagy and Wardowski, 1988). Also, grapefruit (*Citrus paradisi*) that was grown under warmer temperatures (i.e., in Arizona) had a lower ascorbic acid content as compared to grapefruit grown under cooler temperatures (i.e., in California) (Nagy and Wardowski, 1988).

The application of K fertilizer has also been shown to increase ascorbic acid in crops by 8-20% (Welch, 2002). In citrus, the application of K fertilizer was associated with an improved concentration of vitamin C in the juice (Nagy and Wardowski, 1988). In addition to light, temperature, and K supply, ascorbic acid can be affected by such things as soil type. For example, the ascorbic acid content of honeydew muskmelon (*Cucumis melo*) tended to be greater when plants were cultivated on a clay loam as compared to a sandy loam soil (Lester and Crosby, 2002).

In contrast, ascorbic acid content tends to be lower when excessive rates of N fertilizer are applied (e.g., the application of N fertilizer which is greater than that required for maximum plant growth). For example, studies on such crops as potato (*Solanum tuberosum*), cabbage, tomato, grapefruit, orange, lemon (*Citrus limon*), and apple (*Malus* sp.) have shown decreased ascorbic acid content with excessive rates of N fertilizer (Dumas et al., 2003, Weston and Barth, 1997; Nagy and Wardowski, 1988). In a study on yellow grape tomato, as the application rate of N fertilizer increased from 0 to 392 kg ha^{-1}, the concentration of ascorbic acid decreased from 44 to 35 mg 100 g^{-1} (Simonne et al., 2007). In another example, when excess N was applied to the leafy vegetable black nightshade (*Solanum nigrum*) beyond what was needed for optimum growth, the ascorbic acid content decreased (Murage et al., 1996).

Papaya cultivation is currently widespread throughout the tropics and subtropics and has the potential to produce fruit year-round (Manshardt, 1992). It is consumed either green (e.g., as a cooked vegetable or raw in a salad) or ripe (e.g., as a dessert). Ripe papaya is an important source of vitamin A (i.e., provitamin A carotenoids), vitamin C, and folate (Table 4-1). For a 19 to 50 year-old female, a small 150 gram serving of fresh papaya would provide 124%, 14%, and 12% of the

RDA for vitamin C, folate, and vitamin A, respectively (USDA-ARS, 2007; IOM-NAS, 2004). Ncube et al. (2001) showed that supplementing lactating women in Zimbabwe with 650g of pureed papaya daily for 60 days resulted in an improvement in their vitamin A and Fe status.

The vitamin content of green papaya is generally much lower than the vitamin content of ripe papaya (Selvaraj et al., 1982). Selvaraj et al. (1982) determined that both the content of vitamin A and C were generally low until 120 to 130 days after anthesis and then increased dramatically until harvest at 150 days after anthesis. In addition, Mahattanatawee et al. (2006) determined that the total vitamin C content of green cv. Red Lady papaya was nearly three times lower than ripe cv. Red Lady papaya (i.e., 57 mg 100 g^{-1} vs. 154 mg 100 g^{-1}). Although not as nutritious as ripe papaya, the latex from green papaya contains a proteolytic enzyme (i.e., papain) that has several uses including: food preparation (e.g. as a meat tenderizer), leather manufacturing, and as an ingredient in medication and cosmetics (Nakasone and Paull, 1998; Chan, 1983). The overall objective of this study was to evaluate the effect of lime, poultry manure, and micronutrient application on papaya yield, vitamin content, and quality at two different locations in Bangladesh.

Materials and Methods

Between fall 2004 and spring 2006, three field experiments were conducted at two different sites in Bangladesh. Two of the experiments were located in Rangpur and the other was located in Pabna. In Rangpur, the experiments were situated adjacent to each other at the On Farm Research Division, Bangladesh Agricultural Research Institute. The objective of the experiments in Rangpur was to

Table 4-1. Nutritional composition of ripe papaya (USDA-ARS, 2007; IOM-NAS, 2004).

Nutrient	Amount per 150g edible portion	% RDA for female (19-50 y)
Ca	36 mg	3.6
Fe	0.15 mg	0.8
Mg	15 mg	4.8
P	7.5 mg	1.1
K	385.5 mg	0.1
Na	4.5 mg	0.3
Zn	0.105 mg	1.3
Cu	0.024 mg	2.7
Mn	0.0165 mg	0.9
Se	0.9 *ug*	1.6
Vitamin C	92.7 mg	123.6
Thiamin	0.0405 mg	3.7
Riboflavin	0.048 mg	4.4
Niacin	0.507 mg	3.6
Pantothenic acid	0.327 mg	6.5
Vitamin B_6	0.0285 mg	2.2
Folate	57 mg	14.3
Vitamin B_{12}	0 mg	0.0
Vitamin A	82.5 *ug* RAE	11.8
Vitamin E	1.095 mg	7.3
Vitamin K	3.9 *ug*	4.3

evaluate the effect of lime, poultry manure, and planting date on papaya nutrient content and yield. The soil at this site (Bangladesh soil series ‘Gongachara’) was a

silt loam with approximately 40% sand and an acidic pH of 4.0 to 4.7. In Pabna, the experiment was located on a farmer’s field. The objective of this experiment was to evaluate the effect of poultry manure, Zn, and B application on papaya yield and nutrient content. The soil (Bangladesh soil series ‘Sara’) was also a silt loam, but with a lower percentage of sand (i.e., 30%). The pH at this location was more neutral and ranged from approximately 6.0 to 6.2. A description of the initial soil characteristics for each of these experiments is detailed in Table 4-2.

In Bangladesh, there is only one papaya variety named ‘Shahi’. Unfortunately, due to damage from disease and hail, ‘Shahi’ papaya seed is currently unavailable for cultivation (N. Islam, personal communication, 2004). Therefore, for all of the experiments, papaya seed was collected instead from a large papaya grower in Rangpur. The experimental design was a randomized complete block design with four replications. The plant spacing was two meters between rows and two meters between plants in a row. Each plot consisted of nine plants for a total plot size of 36 m^2. In addition, an extra one-half meter between plots was allotted to minimize any potential border effects among plots.

Prior to planting, fertilizer was placed in a round pit that had a diameter of 80 cm and a depth of 40 cm. The fertilizer was incorporated into the soil and then the soil was formed into a mound. Three approximately eight week old seedlings were transplanted onto each mound. At approximately two months after transplanting, excess male and hermaphrodite plants were removed to leave one plant per mound for a total of nine plants per plot. Fertilizer that was applied after transplanting was placed in a ring around each plant at a depth of approximately 5 cm and then covered with surrounding soil.

Table 4-2. Pre-plant soil characteristics of three field experiments in Rangpur and Pabna, Bangladesh.

Property Analyzed	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)	Pabna Experiment
		$mg\ kg^{-1}$	
Total N	620 ± 38†	759 ± 45	527 ± 53†
Morgan P	6.9 ±1.8	37.4 ± 13.7	24.4 ± 1.3
Morgan K	54 ± 1	124 ± 15	79 ± 6
Morgan Ca	76 ± 24	922 ± 177	14464 ± 83
Morgan Mg	8.9 ± 3.7	99 ± 11	238 ± 7
DTPA Cu	1.44 ± 0.19	1.54 ± 0.03	1.25 ± 0.04
DTPA Mn	5.05 ± 0.23	12.29 ± 1.00	11.98 ± 0.31
DTPA Zn	0.68 ± 0.04	3.66 ± 1.47	2.02 ± 0.16
DTPA Fe	65.31 ± 15.00	48.72 ± 8.25	12.88 ± 0.88
DTPA Ni	0.02 ± 0.01	0.04 ± 0.01	0.12 ± 0.01
Morgan Al	95 ± 4	52 ± 5	19.2 ± 0.3
		%	
Total C	0.89 ± 0.08	1.00 ± 0.02	1.30 ± 0.04
Total C (without CO_3)	n/a	n/a	0.55 ± 0.06
pH	4.25 ± 0.07	4.68 ± 0.08	6.19 ± 0.04

† Data calculated from four replications and standard deviation, respectively.

In Bangladesh, papaya is traditionally transplanted in March or April. For the first experiment in Rangpur, papaya seedlings were transplanted in October 2004 (i.e., alternate planting date). For the second experiment, papaya seedlings were transplanted in April 2005 (i.e., traditional planting date). The treatments were the same for both Rangpur experiments and were as follows: treatment one received chemical fertilizer only, treatment two received an additional 1.0 t ha^{-1} dolomite, treatment three received 21 t ha^{-1} poultry manure (i.e., 10 kg poultry manure $plant^{-1}$), and lastly, treatment four received both 21 t ha^{-1} poultry manure and 1.0 t ha^{-1} dolomite. These treatments are referred to as base fertilizer (BF), BF + Lime, BF + Manure, and BF + Manure + Lime. For the first Rangpur experiment (OCT 2004), each of the treatments received 533 kg N ha^{-1}, 186 kg P ha^{-1}, 442 kg K ha^{-1}, 72 kg S ha^{-1}, 7.7 kg Zn ha^{-1}, and 4.7 kg B ha^{-1} each year from urea, triple super phosphate, muriate of potash, gypsum, zinc sulfate, and borax, respectively. For the second Rangpur experiment (APR 2005), each of the treatments received the same fertilizer regime as the first Rangpur experiment with the exception that the B fertilizer application was reduced by one-half (i.e., 2.3 kg B ha^{-1}). For both experiments, urea and muriate of potash were applied monthly, triple super phosphate and poultry manure were applied every six months, and the remainder of the fertilizer was applied prior to transplanting. Poultry manure from sample lot A was applied prior to transplanting and then after six months, the second application of poultry manure was applied as a mulch from sample lot C. The nutrient concentration for each of the sample lots of manure was determined (Table 4-3). Due to the very acidic pH at this location and also the importance of Ca for the ripening of papaya fruit, a supplemental Ca fertilizer application of 0.2 t ha^{-1} dolomite was applied to treatments one and three (Qiu et al., 1995; Nishina et al., 2000).

In Pabna, papaya seedlings were transplanted in April 2005. The treatments were as follows: treatment one received chemical fertilizer only, treatment two received 21 t ha^{-1} poultry manure (i.e., 10 kg poultry manure $plant^{-1}$), treatment three received 21 t ha^{-1} poultry manure and 7.7 kg Zn ha^{-1}, treatment four received 21 t ha^{-1} poultry manure and 4.7 kg B ha^{-1}, and lastly, treatment five received 21 t ha^{-1} poultry manure, 7.7 kg Zn ha^{-1} and 4.7 kg B ha^{-1} per year. These treatments are referred to as BF, BF + Manure, BF + Manure + Zn, BF + Manure + B, and BF + Manure + Zn,B. Each of the treatments received 533 kg N ha^{-1}, 186 kg P ha^{-1}, 442 kg K ha^{-1}, 72 kg S ha^{-1} from urea, triple super phosphate, muriate of potash, and gypsum, respectively. Urea and muriate of potash were applied monthly, triple super phosphate and poultry manure were applied every 6 months, and the remainder of the fertilizer was applied prior to planting. For the manure application, poultry manure from sample lot B was applied prior to transplanting. After six months, the second application of poultry manure was applied as a mulch from sample lot C. The description and experimental design for each of the experiments in Rangpur and Pabna are summarized in Table 4-4.

Fruit was harvested from August 2005 to March 2006 for the first experiment in Rangpur (OCT 2004), from October 2005 to early April 2006 for the second experiment in Rangpur (APR 2005), and from October 2005 to early April 2006 for the experiment in Pabna. For the fruit analyses, fruit was collected between November 2005 and February 2006 for the experiments in Rangpur and during January 2006 and February 2006 for the experiment in Pabna. Papaya fruit was collected at the color-break stage and allowed to ripen at room temperature for one to two days. The fresh weight, pulp weight, seed weight, length, and circumference of each papaya were recorded (Table 4-5). One sample was composed of three fruit from three different papaya plants from each plot. Papaya samples were then

Table 4-3. Analysis of poultry manure collected from Gazipur, Bangladesh.

	Sample Lot A	Sample Lot B	Sample Lot C
Property Analyzed	Total Element Concentration		
	----------	g kg^{-1}	----------
N	9.9 ± 0.4†	11.4 ± 1.0	6.7 ± 0.8
P	13.7 ± 4.5	5.5 ± 0.9	2.7 ± 0.5
K	6.7 ± 0.8	8.7 ± 0.4	5.9 ± 0.7
Ca	160.8 ± 17.6	85.7 ± 4.0	119.0 ± 21.5
Mg	10.6 ± 0.8	11.4 ± 0.3	7.5 ± 0.3
	----------	mg kg^{-1}	----------
Cu	70.0 ± 6.5	79.5 ± 4.9	74.6 ± 8.5
Mn	102.5 ± 44.9	1834.4 ± 205.3	1116.8 ± 565.6
Zn	259.7 ± 76.0	336.3 ± 57.2	217.1 ± 22.0
Fe	1227.1 ± 745.6	2289.9 ± 659.2	833.4 ± 767.4
Mo	0.26 ± 0.14	0.45 ± 0.02	0.45 ± 0.05
	----------	----------	----------
C:N	10.8 ± 0.5	8.7 ± 1.1	16.3 ± 1.1
	----------	%	----------
C	10.7 ± 0.9	9.9 ± 0.5	10.9 ± 1.7
Dry matter	69.7 ± 1.0	55.3 ± 6.9	64.6 ± 3.7

† Data calculated from four replications and standard deviation, respectively.

Table 4-4. Description of three field experiments in Rangpur and Pabna, Bangladesh.

Name:	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)	Pabna Experiment
Design:	RCB	RCB	RCB
Replications:	4	4	4
Plot size:	36 m^2	36 m^2	36 m^2
Plants $plot^{-1}$:	9	9	9
Transplant Date:	October 2004	April 2005	April 2005
Treatments:			
1	BF	BF	BF
2	BF + Lime	BF + Lime	BF + Manure
3	BF + Manure	BF + Manure	BF + Manure + Zn
4	BF + Manure + Lime	BF + Manure + Lime	BF + Manure + B
5			BF + Manure + Zn,B

Table 4-5. Characteristics of papaya fruit sampled for Rangpur experiment (OCT 2004), Rangpur experiment (APR 2005), and Pabna experiment.

Rangpur Experiment (OCT 2004)

Treatment	Fresh wt	Pulp wt	Seed wt	Length	Circumference
	------- kg -----	----- kg ----	----- kg ----	-- cm --	------ cm -------
BF	0.80 ± 0.16†	0.47 ± 0.12	0.06 ± 0.03	17 ± 1	33 ± 4
BF + Lime	1.01 ± 0.22	0.60 ± 0.09	0.07 ± 0.02	18 ± 3	36 ± 1
BF + Manure	0.92 ± 0.22	0.56 ± 0.13	0.07 ± 0.02	17 ± 1	35 ± 2
BF + Manure + Lime	0.84 ± 0.19	0.48 ± 0.13	0.07 ± 0.02	15 ± 2	36 ± 4

Rangpur Experiment (APR 2005)

Treatment	Fresh wt	Pulp wt	Seed wt	Length	Circumference
	------- kg -----	----- kg ----	----- kg ----	-- cm --	------ cm -------
BF	1.09 ± 0.18	0.59 ± 0.12	0.08 ± 0.01	17 ± 1	41 ± 3
BF + Lime	0.97 ± 0.11	0.49 ± 0.05	0.07 ± 0.03	16 ± 1	38 ± 2
BF + Manure	1.37 ± 0.18	0.75 ± 0.09	0.09 ± 0.04	19 ± 1	42 ± 2
BF + Manure + Lime	1.22 ± 0.51	0.63 ± 0.27	0.08 ± 0.04	18 ± 3	41 ± 7

Pabna Experiment

Treatment	Fresh wt	Pulp wt	Seed wt	Length	Circumference
	------- kg -----	----- kg ----	----- kg ----	-- cm --	------ cm -------
BF	1.68 ± 0.17	1.04 ± 0.19	0.09 ± 0.02	20 ± 1	46 ± 2
BF + Manure	1.43 ± 0.17	0.78 ± 0.16	0.10 ± 0.02	19 ± 1	43 ± 1
BF + Manure + Zn	1.45 ± 0.20	0.82 ± 0.16	0.10 ± 0.01	20 ± 1	44 ± 2
BF + Manure + B	1.72 ± 0.47	1.00 ± 0.33	0.10 ± 0.03	20 ± 2	47 ± 5
BF + Manure + Zn,B	1.59 ± 0.61	0.95 ± 0.37	0.09 ± 0.03	20 ± 2	45 ± 8

† Data calculated from four replications and standard deviation, respectively.

prepared according to the method of Godoy and Rodriguez-Amaya (1990) and Kimura et al. (1991), namely, each of the papayas were sliced lengthwise into quarters, the pulp was removed, and the opposite quarters were used for analysis. The papaya samples were pureed and brix was measured using a hand held brix refractometer with automatic temperature compensation (Fisher Scientific, China). Samples were then stored in a 20˚C freezer until they were brought to the U.S.A. for vitamin analyses.

The provitamin A carotenoid and vitamin C content were determined using the procedure by Wall (2006). In order to determine the vitamin C content, 40 g of each sample was blended with 100 mL of cold meta-phosphoric acid-acetic acid solution, which was composed of 30 g meta-phosphoric acid, 80 mL glacial acetic acid, and 0.5 g EDTA in 1 L of distilled water, for three minutes under subdued light. After which, 20 mL of the mixture was centrifuged at 4,000 rpm for 30 minutes in a cold (4˚C) centrifuge. The supernatant was collected and 5mL was passed through C-18 Sep-Paks. Before passing the sample through, the C-18 Sep-Paks were prepared by first passing through 2 mL acetonitrile and then 5 mL distilled water. Samples were then filtered through 0.22 *u*m polycarbonate membranes into amber HPLC vials. Dithioreitol (DTT) at 0.5 mg mL^{-1} was added to reduce any dehydroascorbic acid in the sample to ascorbic acid. Therefore, the total vitamin C content was determined. The extracted samples were then analyzed using HPLC (Wall, 2006).

The total provitamin A carotenoid content was determined by measuring the amount of β-carotene and β-cryptoxanthin in each sample. Under low light and cold temperatures, 20 g of papaya was homogenized for 3 min with 2 g $MgCO_3$, 40 g anhydrous Na_2SO_4, and 75 mL tetrahydrofuran. Samples were then vacumn filtered (i.e., Whatman #4 filter paper) and the remaining residue was then extracted again with another 100 mL tetrahydrofuran. Before storage, the extract was brought to volume and 10 mL was removed and dried under N_2 gas. Prior to HPLC analysis, 0.4 mL tetrahydrofuran was added, the sample was mixed, and then brought to 4 mL volume with 1:1 acetonitrile:methanol solution. Samples were then analyzed using HPLC (Wall, 2006). An analysis of variance was conducted on the data and mean separation was obtained with Duncan's New Multiple Range Test using MSTAT (Freed et al., 1993).

Results and Discussion

In Rangpur, the application of poultry manure substantially increased yield as compared to the non-amended plots (Table 4-6). For the first Rangpur experiment (OCT 2004), the application of manure almost doubled the yield. For the second Rangpur experiment (APR 2005), the application of manure more than doubled the papaya yield. For plants that received manure, the yield was slightly higher for the second Rangpur experiment (APR 2005) as compared to the first experiment in Rangpur (OCT 2004). For example, when manure was applied, plants from the second Rangpur experiment yielded 26 to 28 kg per plant while plants from the first Rangpur experiment yielded approximately 22 to 24 kg per plant (Table 4-6).

For the plots that did not receive manure, more fruit was produced per plant for the first Rangpur experiment (OCT 2004) as compared to the second Rangpur experiment (APR 2005) (Table 4-6). In the first Rangpur experiment, papaya plants from the base fertilizer and base fertilizer with lime treatments produced 19 to 21 fruit per plant, while in the second experiment, papaya plants only yielded 12 to 13 fruit per plant. When manure was applied, the plants produced about the same quantity of fruit (e.g., 31-33 fruit per plant) irrespective of the planting date. Papaya plants from the first Rangpur experiment (OCT 2004) were transplanted six months

Table 4-6. Papaya yield, quantity of fruit produced, and mean fruit weight for Rangpur experiment (OCT 2004), Rangpur experiment (APR 2005) and Pabna experiment.

Rangpur Experiment (OCT 2004)

Treatment	Yield	Quantity	Mean fruit weight
	----- kg plant^{-1} -----	- no. of fruit plant^{-1} -	---------- kg ---------
BF	10.8 b†	19 b	0.58
BF + Lime	13.6 b	21 b	0.68
BF + Manure	23.8 a	33 a	0.72
BF + Manure + Lime	22.2 a	31 a	0.75

Rangpur Experiment (APR 2005)

Treatment	Yield	Quantity	Mean fruit weight
	----- kg plant^{-1} -----	- no. of fruit plant^{-1} -	---------- kg ---------
BF	8.8 b	12 b	0.80
BF + Lime	10.1 b	13 b	0.82
BF + Manure	26.0 a	31 a	0.90
BF + Manure + Lime	28.1 a	33 a	0.89

Pabna Experiment

Treatment	Yield	Quantity	Mean fruit weight
	----- kg plant^{-1} -----	- no. of fruit plant^{-1} -	---------- kg ---------
BF	42.9‡	35 bc	1.20
BF + Manure	35.7	33 c	1.12
BF + Manure + Zn	36.9	34 bc	1.09
BF + Manure + B	41.5	38 ab	1.11
BF + Manure + Zn,B	41.4	40 a	1.10

† Within a column for the Rangpur Experiments, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test.

‡ Within a column for the Pabna Experiment, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

before the papaya plants from the second Rangpur experiment (APR 2005), and therefore it would be expected for these plants to produce more fruit.

Organic amendments (e.g. animal manures) have the potential to increase the organic matter content of the soil. An improvement in soil organic matter content is generally associated with reduced bulk density, increased water holding capacity, and improved fertility and quality of the soil (Brady and Weil, 1996). For these reasons, organic amendments have the potential to increase crop yield (Weil and Magdoff, 2004). Most likely, the application of poultry manure in Rangpur improved the existing soil conditions which resulted in increased yield at this site.

Papaya can be cultivated on a wide range of soils, but prefers soil with a pH between 5.0 and 7.0. In earlier studies, the application of lime to acidic soil was shown to improve papaya yield (Nakasone and Paull, 1998; Awada et al., 1975). In fact, results from an experiment in Hawaii suggest that the application of lime has the potential to increase papaya yield seven-fold as compared to non-amended plots (Younge and Plucknett, 1964). In Rangpur, the application of lime did not improve the amount and/or quantity of papaya produced for either of the Rangpur experiments (Table 4-6). It is possible that a much greater application rate of lime is necessary under these conditions to increase papaya yield.

Animal manure typically contains between 2 to 5% Ca (Havlin et al., 2005). However, the poultry manure used in this study contained 14% Ca and provided roughly 2900 kg Ca ha^{-1}. This is equivalent to more than 10 times the amount of Ca as the lime treatment. Presumably, this high rate of Ca application increased the soil pH and therefore had a beneficial impact on papaya growth and yield.

In addition, fall planting provided ripe papaya approximately four to eight weeks earlier than papaya plants that were transplanted at the traditional time (i.e., March and April). For the first experiment in Rangpur (OCT 2004), the harvest of ripe papaya began in August 2005. Acute human malnutrition tends to be highest during June through August in Bangladesh, and therefore fall planting of papaya would provide vitamin A at a critical time during the year (FAO, 1999).

In Bangladesh, an estimated 85% and 69% of soils are deficient in Zn and B, respectively (Graham et al., 2007). The application of Zn and B fertilizer has been shown to improve papaya yield in India (Kavitha et al., 2000). In Pabna, the application of poultry manure, Zn, or B did not significantly increase yield (Table 4-6). However, the application of manure, Zn, and B tended to increase the quantity of fruit produced per plant. For example, the application of manure, Zn, and B produced more fruit per plant than the base fertilizer, manure only, and manure with Zn treatment. Even though the same amount of inorganic fertilizer (i.e., urea, muriate of potash, triple super phosphate, and gypsum) was applied in both Pabna and Rangpur, this fertilizer regime was only adequate to maximize papaya yield in Pabna.

Although papaya is currently grown throughout Bangladesh, a greater amount of papaya is cultivated in the Pabna area as compared to Rangpur. In this study, the papaya yield in Pabna was substantially greater than in Rangpur. For example, the average yield in Pabna ranged from 36 to 43 kg per plant, while the average yield in Rangpur ranged from only 9 to 28 kg per plant (Table 4-6).

Therefore, if approximately 85% of the papaya plants were female, the papaya plants in Pabna provided 70 tons of ripe papaya per hectare. For the plants that received manure in Rangpur, these plants yielded approximately 45 t ha^{-1}. Lastly, for the plants that did not receive manure in Rangpur, these plants only produced 18 t ha^{-1}. However, all of the experiments had higher yields as compared to national average of 6.6 t ha^{-1} in Bangladesh (FAOSTAT, 2005).

Brix represents the overall sweetness of the papaya fruit and is therefore an important indicator of quality. Even though there were large differences in papaya yield among treatments in Rangpur, there was only a very limited treatment effect on the brix values for papaya (Table 4-7). Similarly, the application of poultry manure, Zn, and B did not affect the brix values of papaya in Pabna. Brix ranged from 9 to 10 in Rangpur and from 6 to 7 in Pabna (Table 4-7). Both of these values are lower than the brix values published for Hawaiian papaya (i.e., 11-14) (Wall, 2006).

Vitamin concentration in plants may be affected by such things as: climate, light intensity, agricultural management practices, soil conditions, and crop maturity (Salunkhe and Desai, 1988). In Rangpur, the application of lime and/or poultry manure did not affect the ascorbic acid content of papaya (Table 4-8). In Pabna, the application of manure alone or manure with B depressed the ascorbic acid content of papaya as compared to the base fertilizer and manure plus Zn and B treatments (Table 4-8). The vitamin C content ranged from 13 to 21 mg 100 g^{-1} in Rangpur and from 6-14 mg 100 g^{-1} in Pabna. This ascorbic acid content is lower than other published values for papaya from Hawaii (i.e., 45 to 65 mg 100 g^{-1}), from Singapore (i.e., 45 to 68 mg 100 g^{-1}), and from India (i.e., 47 to 78 mg 100 g^{-1}) (Wall, 2006; Leong and Shui, 2002; Selvaraj et al., 1982). Although the papaya samples used in this study were kept frozen prior to analysis, vitamin C is extremely sensitive to environmental changes. During storage, ascorbic acid can be oxidized to dehydroascorbic acid, and then possibly broken down further into 2,3-diketogulonic acid. This compound (i.e., 2,3-diketogulonic acid) does not have any vitamin C activity (Combs, 1998; Crawley, 1993). In other studies, losses of ascorbic acid during frozen storage have ranged from 35 to 55% in potato and from approximately 20 to 50% for broccoli (*Brassica oleracea*) and spinach (*Spinacia oleracea*) (Dale et al., 2003; Rickman et al., 2007). For this study, it is possible that the vitamin C

Table 4-7. Determination of soluble solids (˚Brix) for ripe papaya sampled from Rangpur experiment (OCT 2004), Rangpur experiment (APR 2005), and Pabna experiment.

	Rangpur Experiment (OCT 2004)
Treatment	Soluble solids (˚Brix)
	--
BF	9.2†
BF + Lime	9.7
BF + Manure	9.2
BF + Manure + Lime	9.0
	Rangpur Experiment (APR 2005)
Treatment	Soluble solids (˚Brix)
	--
BF	9.0 b
BF + Lime	10.5 a
BF + Manure	10.1 a
BF + Manure + Lime	9.0 b
	Pabna Experiment
Treatment	Soluble solids (˚Brix)
	--
BF	7.3
BF + Manure	6.4
BF + Manure + Zn	6.8
BF + Manure + B	7.5
BF + Manure + Zn,B	7.3

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table 4-8. Determination of ascorbic acid content of ripe papaya sampled from Rangpur experiment (OCT 2004), Rangpur experiment (APR 2005), and Pabna experiment.

	Rangpur Experiment (OCT 2004)
Treatment	Ascorbic acid content
	------------------------------ $mg\ 100\ g^{-1}$ ------------------------------
BF	13.4
BF + Lime	19.3
BF + Manure	16.8
BF + Manure + Lime	13.6

	Rangpur Experiment (APR 2005)
Treatment	Ascorbic acid content
	------------------------------ $mg\ 100\ g^{-1}$ ------------------------------
BF	15.5
BF + Lime	20.8
BF + Manure	19.3
BF + Manure + Lime	13.0

	Pabna Experiment
Treatment	Ascorbic acid content
	------------------------------ $mg\ 100\ g^{-1}$ ------------------------------
BF	11.2 ab†
BF + Manure	6.4 b
BF + Manure + Zn	11.0 ab
BF + Manure + B	8.0 b
BF + Manure + Zn,B	13.4 a

† Within a column, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

content of the papaya samples decreased during storage in Bangladesh prior to vitamin analysis in the U.S.A.

The provitamin A carotenoid content of papaya was not affected by either lime or poultry manure application in Rangpur (Table 4-9). In Pabna, the plots which only received manure tended to have the highest concentration of β-carotene, β-cryptoxanthin, and thus provitamin A carotenoid retinol activity equivalents (RAE) (Table 4-9). In this situation, applying Zn and B did not improve the carotene content of papaya. Based on an earlier study with carrot, plants that received B fertilizer had a greater carotenoid content in the roots as compared to plants which did not receive B (Grunes and Allaway, 1985). However, the carrot plants were deficient in B. In Pabna, the lack of yield response to B fertilization would suggest that soil B level was adequate for papaya production.

The provitamin A carotenoid content ranged from 22 to 45 *u*g RAE 100 g^{-1} in Rangpur and from 11 to 20 *u*g RAE 100 g^{-1} in Pabna (Table 4-9). The vitamin A content of Bangladeshi papaya is somewhat lower than Hawaiian papaya (i.e., 19-74 *u*g RAE 100 g^{-1}), but generally within their published values (Wall, 2006). In the present study, β-carotene ranged from 56 to 251 *u*g 100 g^{-1} and β-cryptoxanthin ranged from 143 to 588 *u*g 100 g^{-1}. In comparison, data from the USDA-NCC carotenoid database showed that the values for β-carotene and β-cryptoxanthin in papaya ranged from 62-910 *u*g 100 g^{-1} and 517-1264 *u*g 100 g^{-1}, respectively (USDA, 1998). Also, for Brazilian papaya, the values for β-carotene ranged from 60 to 810 *u*g 100 g^{-1} and β-cryptoxanthin ranged from 400-1260 *u*g 100 g^{-1} (Kimura et al., 1991). And lastly, from a study on papaya in Indonesia, values for β-carotene ranged from 322 to 664 *u*g 100 g^{-1} and β-cryptoxanthin ranged from not detected to 425 *u*g 100 g^{-1} (Setiawan et al., 2001). The provitamin A carotenoid content of

Table 4-9. Determination of carotenoid content of ripe papaya from Rangpur experiment (OCT 2004), Rangpur experiment (APR 2005), and Pabna experiment.

	Rangpur Experiment (OCT 2004)		
Treatment	β-Carotene	β -Cryptoxanthin	Provitamin A Carotenoids
	----- *u*g 100 g^{-1} ----	----- *u*g 100 g^{-1} -----	--- *u*g RAE 100 g^{-1} --
BF	145.9†	403.0	29.0
BF + Lime	207.8	444.6	35.9
BF + Manure	176.8	398.7	31.3
BF + Manure + Lime	178.9	441.5	33.3

	Rangpur Experiment (APR 2005)		
Treatment	β-Carotene	β -Cryptoxanthin	Provitamin A Carotenoids
	----- *u*g 100 g^{-1} ----	----- *u*g 100 g^{-1} -----	--- *u*g RAE 100 g^{-1} --
BF	109.8	316.4	22.3
BF + Lime	195.5	558.1	39.6
BF + Manure	250.5	588.2	45.4
BF + Manure + Lime	168.1	403.9	30.8

	Pabna Experiment		
Treatment	β-Carotene	β -Cryptoxanthin	Provitamin A Carotenoids
	----- *u*g 100 g^{-1} ----	----- *u*g 100 g^{-1} -----	--- *u*g RAE 100 g^{-1} --
BF	60.9 b	169.6	12.1 b
BF + Manure	89.2 a	288.7	19.5 a
BF + Manure + Zn	55.9 b	142.7	10.6 b
BF + Manure + B	61.9 b	175.1	12.5 b
BF + Manure + Zn,B	67.7 b	231.5	15.3 ab

† Within an experiment and column, means followed by the same letter are not different at $p \leq 0.10$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

papaya from Bangladesh, for the most part, is similar to the provitamin A content of papaya from other countries.

Assuming that at least one-half of the total fresh weight of papaya is edible (Table 4-5), one hectare of papaya in Pabna would provide 4.9 x 10^6 *u*g RAE under these conditions. For the plants that did not receive poultry manure in Rangpur, one hectare of papaya would provide 2.9 x 10^6 *u*g RAE. Interestingly, for the plants that received manure in Rangpur, one hectare of papaya would provide 7.9 x 10^6 *u*g RAE. Even though the overall fruit yield was higher in Pabna as compared to Rangpur, the papaya plants that received poultry manure in Rangpur would supply a greater amount of vitamin A. Therefore, the agricultural yield may be higher in Pabna, but the "nutrient yield" has the potential to be greater in Rangpur.

In conclusion, the application of poultry manure either almost doubled or more than doubled the papaya yield in Rangpur. Papaya that was transplanted in the fall provided ripe fruit approximately four to eight weeks earlier than papaya transplanted in the spring. In Pabna, the application of poultry manure, Zn, and/or B had a very limited effect on crop yield. Although there was very little difference in brix and vitamin content among the treatments for either location, the papaya fruit from Rangpur tended to have higher brix and vitamin content as compared to fruit from Pabna.

It is possible that the unavailability of a "true" cultivar of papaya in Bangladesh may be contributing to variability in papaya vitamin content and quality. In addition, climactic and soil conditions vary between Pabna and Rangpur and this may account for some of the differences seen in this study. Additional studies in other locations in Bangladesh are needed to fully understand these differences.

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CHAPTER FIVE

SUMMARY AND CONCLUSIONS

Papaya is currently cultivated throughout Bangladesh and has the potential to produce fruit year-round (Manshardt, 1992). It is a large herbaceous plant that can be grown on a wide range of soils. However, it prefers soils with good drainage and a pH between 5.0 and 7.0 (Nakasone and Paull, 1998; Nishina et al., 2000). Papaya is generally consumed either green (e.g., as a cooked vegetable) or ripe (e.g., as a dessert). Ripe papaya is an important source of vitamin A (i.e., provitamin A carotenoids), vitamin C, and folate (USDA-ARS, 2007). In Bangladesh, the average yield of papaya is extremely low as compared to other papaya producing countries (FAOSTAT, 2005).

Micronutrient malnutrition (e.g., vitamin A, iodine (I), iron (Fe), and zinc (Zn) deficiencies) is a significant health problem worldwide. In rural Bangladesh, an estimated 50% of all children and women of reproductive age are deficient in vitamin A and Fe (Talukder et al., 2000). One strategy to improve the nutritional status of deficient individuals is to increase the production and availability of vitamin-rich fruits and vegetables.

Over a two and one-half year period, eight field experiments at two different locations (i.e., Pabna area and Rangpur) were conducted in an effort to improve papaya production in Bangladesh. The overall objective of this study was to evaluate the effect of nutrient management, planting date, and location on plant nutrition, soil properties, and papaya yield and quality.

In Rangpur, three field experiments were conducted at the On Farm Research Division, Bangladesh Agricultural Research Institute. The soil at this location was a silt loam (i.e., 40% sand, 52% silt, 8% clay) with an acidic pH of 4.0 to 4.7. For the first, second, and third experiment in Rangpur, the papaya seedlings were transplanted in April 2004, October 2004, and April 2005, respectively. Papaya is traditionally transplanted in March or April in Bangladesh and therefore, the October transplant date represents an alternate planting date for papaya cultivation.

Each of the three experiments received the same four treatments: chemical fertilizer, chemical fertilizer with lime, chemical fertilizer with poultry manure, and chemical fertilizer with lime and poultry manure. The experimental design was a randomized complete block design with four replications. Each plot had nine plants with a total plot size of 36 m^2.

In Rangpur, the application of poultry manure substantially increased papaya yield. Depending upon the experiment, the yield was either almost doubled or more than doubled when manure was added. Poultry manure application also generally increased the soil concentration of phosphorus (P), calcium (Ca), magnesium (Mg), and Zn and the petiole concentration of P, Ca, Mg, and potassium (K). In contrast, the application of poultry manure lowered the soil concentration of aluminum (Al) and the petiole concentration of manganese (Mn) and Zn. Also, the application of manure was generally needed to prevent P deficiency at this location. For these experiments, the application of lime had a very limited effect on yield, plant nutrition, and soil properties. Overall, the application of poultry manure greatly improved yield and is most likely the result of an increased soil pH, a reduced concentration of soil Al, and an improved concentration of plant P associated with manure application.

In Rangpur, papaya that was transplanted in the fall provided ripe fruit approximately four to eight weeks earlier than papaya transplanted in the spring. Acute human malnutrition tends to be highest during June through August in

Bangladesh, and therefore fall planting of papaya would provide vitamin A at a critical time during the year (FAO, 1999).

In addition, another five field experiments were conducted in Pabna and Ishurdi, Bangladesh. In Pabna, three field experiments were located in close proximity to each other on a farmer's field and an additional experiment was located at the Pabna On Farm Research Division, Bangladesh Agricultural Research Institute. In Ishurdi, one experiment was located on a farmer's field. The soil at the three farmer field experiments in Pabna was a silt loam (i.e., 29% sand, 62% silt, and 9% clay) with pH of 5.9 to 6.2. At the Pabna research station, the soil was a silt loam (i.e., 38% sand, 54% silt, and 8% clay) with a more neutral pH of 7.2. The soil in Ishurdi was a silty clay loam (i.e., 4% sand, 56% silt, 40% clay) with a slightly acidic pH of 5.8. The overall objective of these experiments was to evaluate the effect of poultry manure, Zn, and boron (B) on papaya yield.

In Pabna and Ishurdi, even though the application of poultry manure tended to improve the soil fertility at these sites, the application of poultry manure, Zn, and/or B had a very limited effect on crop yield. Unfortunately, the Pabna experiment at the research station was damaged by floods and the Ishurdi experiment was severely infected with papaya ringspot virus. For the farmer field experiments in Pabna, the inorganic fertilizer regime was generally adequate to maximize yield at this location.

Vitamin concentration in plants may be affected by such things as: climate, light intensity, agricultural management practices, soil conditions, and crop maturity (Salunkhe and Desai, 1988). In order to evaluate the effect of nutrient management, planting date, and location on the vitamin content of papaya in Bangladesh, ripe papaya was sampled from three field experiments (i.e., two experiments from Rangpur and one experiment from Pabna). The results from this study suggest that there was very little difference in brix and vitamin content among the treatments for either location, however, the papaya fruit from Rangpur tended to have higher brix and vitamin content as compared to fruit from Pabna.

Due to the damage of the Pabna research station experiment and the Ishurdi experiment, the papaya yield for these two experiments only ranged from 5 to 14 t ha^{-1} and 9 to 20 t ha^{-1}, respectively. The papaya yield in Rangpur ranged from 16 to 51 t ha^{-1} and in Pabna for the farmer field experiments ranged from 50 to 78 t ha^{-1}. Overall, all of the experiments generally had much higher yields than the national average of 6.6 t ha^{-1} for papaya in Bangladesh (FAOSTAT, 2005).

In conclusion, the results from this study suggest that a combination of nutrient management and planting date has the potential to improve the production and availability of papaya in Bangladesh. Supplementary studies are needed to explain the observed differences in papaya vitamin content and quality between locations. Also, in order to improve the nutritional status of micronutrient deficient individuals, additional research is needed to improve the crop yield of other vitamin-rich fruits and vegetables in Bangladesh.

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APPENDIX

Table A-1. Effect of lime and poultry manure on ratings of PRSV for Rangpur experiment (APR 2004), Rangpur experiment (OCT 2004), and Rangpur experiment (APR 2005) located at Rangpur OFRD, Bangladesh. (For PRSV ratings, a rating of one represents a plant that was severely affected by PRSV and a rating of five represents a plant that was not affected by PRSV.)

Treatment	Rangpur Experiment (APR 2004)	Rangpur Experiment (OCT 2004)	Rangpur Experiment (APR 2005)
BF	2.8†	3.0	2.8
BF + Lime	3.5	2.9	3.5
BF + Manure	2.0	3.8	3.7
BF + Manure + Lime	3.3	3.3	3.5

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.

Table A-2. Effect of Zn, B, and poultry manure on ratings of PRSV for the Pabna and Ishurdi experiments. (For PRSV ratings, a rating of one represents a plant that was severely affected by PRSV and a rating of five represents a plant that was not affected by PRSV.)

Treatment	Pabna Experiment	Ishurdi Experiment
BF	3.5†	2.3
BF + Zn, B	4.0	2.8
BF + Manure	3.0	2.8
BF + Manure + Zn, B	3.3	2.0
Manure only	3.0	2.3

† Within an experiment, means followed by the same letter are not different at $p \leq 0.05$ according to Duncan's New Multiple Range Test. The absence of letters indicates that the effect was not significant.