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Tomato Fruit Yield, Quality and Shelf Life Improvement through Organic and Inorganic Fertilization

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Abstract **– Tomato fertilization system was optimized involving farmers as technology users. Seven different rates of fertilizer application were documented in a survey of farmers in a vegetable-growing area in Central Philippines. They served as basis for the fertilizer treatments (3 organic fertilizer levels using chicken dung or CD and 4 inorganic fertilizer levels using complete fertilizer 14-14-14) tested in on-farm trials in the dry season (December to May) and wet season (June to November) co-managed by farmers. Other cultural practices were those employed by farmers with modifications by introducing good practices. Optimum fertilization rate was 4.7 tons CD/ha + 93-93-93 for dry season crop and 2.3 tons CD/ha + 93-93-93 for wet season crop, giving fruit yields of 28.9 tons/ha and 15.4 tons/ha, respectively, or more than 3-fold higher than that of unfertilized crop, 7.5 and 4.2 tons/ha, respectively. Fertilization did not affect fruit size and titratable acidity but increased fruit weight and total soluble solids, and during ambient storage, reduced weight loss, delayed ripening and extended shelf life by 2-4 days more. Economic analysis revealed very high profitability of organic-inorganic fertilization with net profit-cost ratio of more than 1.0.**

Keywords – Solanum lycopersicum L,. **Crop Productivity, Plant Nutrition, Participatory Research.**

I. Introduction

Tomato is one of the most widely consumed vegetables in the world and a priority vegetable of the Philippine government (DA-BAR RDEAP 2016-2022). It is rich in vitamins A and C, folic acid and minerals (calcium, phosphorus and iron) and contains high amounts of antioxidants, such as lycopene and other carotenoids, polyphenols, ascorbic acid, alpha-lipoic acid and choline (Dumas et al., 2003; Saltveit, 200). Increasing production of tomato and other high-value nutrient-dense crops could support food and nutrition security, poverty alleviation and resilience to crises.

Nutrient supply is critical to increasing crop productivity. A balanced supply of plant nutrients is required but conventional farming relies heavily on the use of chemical fertilizers which risks the health of soils (e.g. increased acidity, loss of organic matter and nutrient imbalance), environment (e.g. groundwater or surface water contamination with toxic chemicals and biodiversity loss) and people (Loreau et al., 2001; Tilman et al., 2002; Kaur et al., 2005). Ecofriendly agricultural practices are crucial for sustainable production. Among sustainable practices, organic amendment can restore, maintain or increase soil organic matter which is the very foundation for healthy and productive soils (Zink et al, 1998; Magdoff and Van Es, 2010; Scotti et al., 2015). A healthy soil delivers multiple ecosystem services, such as sustaining water quality and crop productivity, controlling nutrient recycling and removing greenhouse gases (Tabat et al., 2020).

Nutrient management determines crop yields (Silva, 1986; Yadav et al., 2001; Kaur et al., 2005). Several studies examined the effects of organic fertilizer with or without inorganic fertilizer in tomatoes but findings were not consistent (Blatt, 1991; Kaur et al., 2005; Chassy et al., 2006). Some studies have shown that organic amendments improved growth and yield and increased the antioxidants, total phenolics, ascorbic acid and soluble solids contents of tomatoes (Chassy et al., 2006; Toor et al., 2006). Furthermore, in most fertilization studies, fertilizer effects are determined based on growth and yield responses. Less attention has been given to fertilizer effects on product quality and shelf life. Harvest and postharvest quality of crops is determined by the conditions during growth and development in the field (Monselise and Goren, 1987). Producing crops with desirable harvest and postharvest quality could increase product marketability and farm profits.

Crop production technologies such as fertilization system can be easily adopted if they suit farmers' conditions. However, technology adoption among small farmers has been a problem in the conventional research-extension-utilization process where researchers develop technologies at research stations, extension workers spread them, and farmers adopt or reject them (Gonsalves et al., 2005). The problem persisted despite strategic extension system, such as the Training and Visit System. The main cause was that the technologies were not appropriate for farmers. As a sustainable solution to this problem, participatory research was introduced as an approach aimed at creating appropriate technology for small farmers. It responds to problems and needs of farmers; develops technology options that build on local knowledge and resources; and ensures that technologies developed are appropriate for farmers (Caldwell, 2001; Pimbert, 2011). This research employed a participatory approach to optimizing fertilization of tomato to improve fruit yield, quality and shelf life.

II. MATERIALS AND METHODS

Participatory Approach

The research engaged tomato farmers in a major vegetable-growing area to assess and optimize the fertilization practice (Acedo and Benitez, 2019). The fertilization practices and fertilizer treatments for testing in the optimization trials were discussed and validated with farmers. The experimental trials were conducted at farmer's field employing farmer-researcher co-management. The rationale was that the change to be introduced is not entirely new to farmers as it only involves adjustment of an existing practice; farmers can have first-hand involvement in making and experiencing the results of the change; and the activity builds the capacity of farmers. Thus, technology adoption could be facilitated.

Study Site

The study site is a major vegetable-growing area in Central Philippines (Visayas) comprising of upland villages of the coastal city of Ormoc, Leyte (geographic coordinates 11.0384° N, 124.6193° E; altitude 5.6 meters above sea level). These upland villages are near the Energy Development Corporation's Tongonan Geothermal Project which is the world's largest wet steam field. On-farm trials were conducted with farmers in the village of Cabintan (11.0947° N, 124.6884° E; 838.4 meters above sea level).

Survey of Fertilization Practices

A questionnaire was formulated, pretested and finalized for the survey of farming practices of tomato farmers in the aforementioned vegetable-growing area with emphasis on fertilization practices and associated cultural management operations. Twenty five farmer-respondents were randomly sampled. Results of the survey are reported here as frequencies and percentages.

On-farm Trials

The different fertilizer treatments were formulated based on the fertilization practices of farmers. Other good cultural practices including the tomato variety used, seedling production, and control of weeds, insect pests and diseases were essentially those employed by majority of the farmers surveyed. Plant survival was maintained at more than 90% by reserving seedlings for replanting within one week from transplanting. Before field planting, soil samples from up to 15 cm depth at strategic locations of the experimental area were taken for analysis of pH, organic matter, total nitrogen (N), available phosphorus (P) and available potassium (K). The field trials were conducted during the dry season (December-May) and wet season (June-November) with the first month devoted to seedling production; the succeeding months for field growing until harvest; and the last month for postharvest evaluation. Standard experimental protocols were followed including experimental design, number of replications, plot size per replicate and randomization.

Fruit Yield, Quality and Shelf Life Evaluation

Fruit yield was taken from the first four harvests at 5-day interval from plants per plot except border plants. Mature green and ripening fruits were harvested by hand observing necessary care to avoid physical injuries. Yield parameters included number and weight of marketable and non-marketable (insect-damaged, diseased, deformed and small sized) fruits. Supportive growth and development parameters (horticultural characteristics) were taken, including number of days to 50% flowering per plot (replicate) and plant height and herbage weight of 10 sample plants per replicate. After taking fruit yield parameters at harvest, fruit samples were taken for quality and shelf life evaluation. Fruit quality parameters using 10 breaker fruits per replicate included fruit length and width measured using a Vernier caliper; weight using a weighing scale; total soluble solids (TSS) using a hand refractometer; and titratable acidity (TA) by the titrimetric method using a standard base (0.1N NaOH) and 1% phenopthalein as indicator. Mature-green fruits (20 fruit per replicate) were used for postharvest evaluation during ambient storage (26-33^{o}C; 65-85% RH). Weight loss was taken as percentage of initial weight. Ripening changes were determined based on peel color development using a color index (CI) of 1-6 (1-green, 2-breaker, first trace of red; 3-turning, more green than red; 4-pink, more red than green; 5-red with trace of green; 6-full red). The number of days to full red (CI 6) was taken as the ripening period. Shelf life was determined as the number of days to reach the limit of marketability using a visual quality rating (VQR) of 9-1 (9-excellent, no defects; 7-good, defects minor; 5-fair, defects moderate, limit of marketability; 3-limit of edibility; 1-inedible under usual condition). Main defects included over-ripening, shriveling and decay.

Statistical Analysis

The results presented are pooled means of two trials per growing season and were statistically analyzed by performing analysis of variance (ANOVA) and treatment mean comparison by the least significance difference test (LSD) at 5% level using MSTAT (Microcomputer Statistical Package, Michigan State University, USA).

III. Results and Discussion

Fertilization Practices

Table 1 shows the demographic characteristics of tomato farmer-respondents of the survey. Most of these farmers were aged 40-50 years old who had not finished elementary education. Over 50% of the respondents had been growing tomato for more than 10 years. Tomato was typically grown in small areas ranging from 0.25-0.5 ha. Majority of the farmers owned their farms. The 'Improved Pope' tomato was the commonly used variety (Table 2). Seedlings were prepared by the cellular method using fresh banana leaves and field planted when 3 weeks old. Plant spacing was usually 30 cm x 100 cm. Weeding was done manually once or twice per cropping depending on weed growth. Commercial insecticides and fungicides were sprayed to the plants mostly at two-week interval. Spraying ceased when the fruits start to mature or one week before harvest. Some farmers watered their plants daily or twice weekly at one liter per plant using a used 1-liter oil can while others depended on rains. The plants were trellised one month after planting using plastic straw or together with thick nylon strands.

All tomato farmers fertilized their plants. Seven different rates of fertilization were obtained (Table 3). Majority of the farmers employed organic-inorganic fertilization. Poultry manure or chicken dung (CD) was used as organic fertilizer at 70-140 g per plant (using a used cylindrical 'sardine' can that can contain 140 g CD when filled) and applied basally at planting. Inorganic fertilizer application was variable, ranging from 53-147 kg N/ha, 47-140 kg P_2O_5/ha and 47-200 kg K_2O/ha. These fertilization rates were calculated based on the amount of fertilizer applied per plant (converting into specific weight the farmers' practice of using a tablespoon as measuring device) and plant spacing. To meet the different rates of inorganic fertilization, complete fertilizer (14-14-14) was commonly used alone or in combination with ammonium phosphate (16-20-0), urea (46-0-0) and/or muriate of potash (0-0-60). The desired amount of fertilizer was divided into two equal parts if CD was used, and into three equal parts if not. Each part was usually applied at two weeks interval starting at the time of field planting.

It is ideal to test all the fertilizer rates employed by farmers but for manageability of the on-farm trials, the fertilizer treatments were limited to the following:

Main treatments (amount of CD as organic fertilizer):

O_1 = 0, no CD.

O_2 = 2.3 tons/ha (0.5 'sardine' can per plant)

O_3 = 4.7 tons/ha (1 'sardine' can per plant)

Sub-treatments (inorganic fertilizer rates):

T_1 = 0-0-0.

T_2 = 47-47-47 (1 tablespoon 14-14-14 per plant)

T_3 = 93-93-93 (2 tablespoon 14-14-14 per plant)

T_4 = 140-140-140 (3 tablespoon 14-14-14 per plant)

Table 1. Demographic characteristics of tomato farmer-respondents.

Demographic Attributes	Frequency		Demographic Attributes	Frequency
1. Age (years)			4. Area of farm (hectare)	
18-28	23.5		1/8	6.2

Demographic Attributes	Frequency		Demographic Attributes	Frequency
29-39	17.7		1/4	50.0
40-50	41.1		1/2	37.5
51-61	17.7		3/4	6.3
2. Educational attainment			5. Tenure status	
Grade 4	60.0		a. Class	
Elementary graduate	20.0		Owner	66.7
High School graduate	20.0		Tenant	33.3
3. Years in farming			b. Sharing system if tenant	
0-10	41.2		None	80.0
11-20	29.4		1/5	20.0
21-30	23.5			
31-40	5.9			

Source: Acedo and Benitez, 2019.

Table 2. Cultural management practices of tomato farmer-respondents.

Cultural Practice	Frequency[1]		Cultural Practice	Frequency[1]
1. Tomato variety used			6. Fungicide spray	100.0
Improved Pope	100.0		a. Frequency	
VC-11	29.4		2 times/week	10.0
Unspecified	11.8		Once a week	30.0
2. Seedling production			Once/2 weeks	60.0
Cellular method	100.0		b. End of spraying	
Other methods	0.0		`1 wk before harvest	50.0
3. Plant spacing (cm)			When fruit mature	50.0
30 x 100	64.7		7. Irrigation	60.0
30 x 60	29.4		a. Amount, 1 liter/plant	60.0
20 x 150	5.9		b. Frequency	
4. Weeding			Daily	36.0
a. Method, manual; based on weed growth	100.0		2 times/week	24.0

Cultural Practice	Frequency[1]		Cultural Practice	Frequency[1]
b. Frequency			8. Trellising	100.0
Once	50.0		a. Materials used	
2 times	40.0		Plastic straws	50.0
3 times	10.0		Nylon + plastic straw	50.0
5. Insecticide spray	100.0		b. Time from transplanting	
a. Frequency			1 month	80.0
2 times/week	10.0		1.5 months	10.0
Once a week	30.0		2 months	10.0
Once/2 weeks	60.0			
b. End of spraying				
1 week before harvest	50.0			
When fruit mature	50.0			

[1] Some items are multiple responses (n = 25); Source: Acedo and Benitez, 2019.

Table 3. Fertilization practices of tomato farmer-respondents.

Rate No.	Fertilization Rate		Fertilizer Used[3]	Frequency[4]
	Organic (tons/ha)[1]	Inorganic (kg/ha)[2]		
1	0	140-140-140	14-14-14	33
2	2.33	53-67-200	Chicken dung (CD); 14-14-14; 16-20-0; 0-0-60	33
3	2.33	93-93-93	CD; 14-14-14	33
4	4.67	100-113-47	CD; 14-14-14; 16-20-0	13
5	4.67	147-47-113	CD; 14-14-14; 46-0-0;0-0-60	13
6	4.67	103-70-70	CD; 14-14-14; 46-0-0	33
7	4.67	70-70-170	CD; 14-14-14; 0-0-60	33

[1] Applied basally per plant at planting (2.33 tons CD/ha = 1/2 'sardine' can CD/plant).

[2] Applied per plant at 2-week interval for 2 times if CD is applied and for 3 times if not.

[3] Complete fertilizer 14-14-14; urea 46-0-0; ammonium phosphate 16-20-0; muriate of potash 0-0-60.

[4] Multiple response (n = 25)

Source: Acedo and Benitez, 2019.

The choice of the three rates of CD application was based on farmers' practice. The inorganic fertilizer levels were within the range used by farmers. The treatments were arranged in split plot design with three replicates

(Gomez and Gomez, 1984). Replicates, main plots and subplots (4m x 5m) were separated by 1m alleyways. As practiced by farmers, the organic fertilizer (CD) was applied basally in each plant at field planting. The inorganic fertilizer amount was divided into two equal parts if CD was used, and into three equal parts if not. Each part was applied at two weeks interval starting at the time of planting. 'Improved Pope' tomato variety was used and the seedlings were produced by the cellular method using seedling trays and transplanted to the field when 3-week old following gradual exposure to field conditions in the nursery (hardening or acclimatization). Other cultural management practices of farmers were followed with some modifications to introduce good practices, including used of sterilized soil for seed germination and seedling production, raised seedbed construction, proper method of trellising, avoiding irrigation later in the afternoon, and proper pesticide spraying following the manufacturer's recommendation or when the need arises based on field observation until two weeks before the first harvest.

Climate and Soil

The study site has Type IV climate in which rainfall is more or less evenly distributed throughout the year (http://bagong.pagasa.dost.gov.ph/information/climate-philippines). During the on-farm trials, monthly rainfall ranged from 20-200 mm in the dry season cropping and 75-243 mm in the wet season cropping. Minimum and maximum temperatures ranged from 18.0-21.8^{o}C and 29.5-32.8^{o}C in the dry season cropping, and 19.0-21.5^{o}C and 29.8-32.5^{o}C in the wet season cropping, respectively. The soil chemical properties differed slightly between dry and wet season plantings. The soil type was silty loam with 6.20-6.23 pH, 3.27-3.33% organic matter, 0.22-0.25% N, 39.8-44.5 mg P/kg and 150.5-170.7 mg K/kg. Optimum soil pH for tomato production is 5.5-6.75 (FAO, 2006) while organic matter content typical of agricultural soils ranged from 1-6% [8]. For most crops, the critical nutrient range that is likely to result in 90% of maximum yield is 1.5-3.5% for N, 0.15-0.40% for P and 1.0-2.5% for K (FAO, 2006). Farmers' fertilization practices are usually not based on soil test results. The amounts of nutrients taken up by previous crops are not a good indication of fertilizer requirements of the current crop because it ignores the nutrient-supplying power of the soil, thus soil analysis before planting is more useful than that after harvest (Hagin and Tucker, 1982).

Horticultural Characteristics

CD as organic fertilizer shortened the time period for the dry season crop to flower, with the application of 4.7 tons CD/ha resulting in significantly shorter time to flowering than that without CD (Table 4). CD at 2.3 tons/ha had similar effect which however did not statistically vary from that without CD. On the other hand, inorganic fertilizer application consistently resulted in earlier flowering but this effect was statistically significant only when fertilizer rates higher than 47-47-47 were used. Plants fertilized with 93-93-93 and 140-140-140 had comparably shorter time to flowering stage which significantly differed from that without inorganic fertilizer.

Plant height increased with organic and inorganic fertilizer application (Table 4). Increasing the rate of CD application to 4.7 tons/ha further increased plant height. Inorganic fertilizer rate of 93-93-93 seemed to be optimum to increase plant height as lower rate (47-47-47) significantly decreased plant height while higher rate (140-140-140) did not further increase plant height. The same trend was obtained for herbage yield which increased with increasing CD rate and was highest when 93-93-93 was applied (Table 4).

In the wet season crop, CD and NPK application also resulted in earlier flowering of the plants relative to the unfertilized treatment (Table 4). CD at 2.3 tons/ha and NPK at 93-93-93 were sufficient to hasten flowering. Plant height markedly increased with CD and NPK application (Table 4). CD at 4.7 tons/ha produced the highest plant height. With NPK application, plant height was highest with 93-93-93. Similarly, herbage weoght increased with CD and NPK application (Table 4). Combined 4.7 tons CD/ha and 93-93-93 produced the heaviest herbage.

Plant nutrition is one of the most important factors that increase plant growth. The results showed that integrated supply of plant nutrients through organic and inorganic fertilizer application improved vegetative growth. The better growth performance of crops in response to combined organic and inorganic fertilizer application has also be obtained in previous studies (Kang and Balasubramanian, 1990; Li et al., 1995). Balanced fertilization using both organic and chemical fertilizers is important for maintenance of soil organic matter content and long-term soil health and crop productivity as opposed to inorganic fertilizer alone or mere application of organic material (Kaur et al., 2005). Previous studies also reported that the use of organic fertilizers together with chemical fertilizers had a higher positive effect on microbial biomass and soil health. Increase in microbial biomass C and N has been observed in soils receiving organic manures alone or in combination with chemical fertilizers compared to soils receiving chemical fertilizers only.

The effects of organic and inorganic fertilization on crop growth depends on the application rates and nature of fertilizers. CD has been reported to contain 2.3-2.9% NPK which is higher than other farm manures and organic residues like compost (FAO, 2006). These nutrients are released for plant absorption upon mineralization of the organic material. Organic fertilizers and the resulting enrichment of soil organic matter content improve soil properties such as soil porosity, water permeability and water-holding capacity, and cation exchange capacity, resulting in enhanced crop growth and yields. On the other hand, N, P and K have different essential roles in growth processes of plants and the application of NPK fertilizer usually promotes plant growth and development.

Table 4. Horticultural characteristics of tomato in response to fertilizer treatment during dry and wet season plantings.

Treatments	Days to Flowering	Plant Height (cm)	Herbage Weight (kg/plant)
Dry season planting			
Chicken dung (main plot)			
0	39.0a	82.7c	0.75c
2.3 tons/ha	35.2ab	96.2b	0.95b
4.7 tons/ha	34.0b	105.0a	1.04a
NPK application (subplot)			
0-0-0	43.3a	65.5c	0.63c
47-47-47	38.5ab	93.4b	0.82b
93-93-93	32.5bc	102.5ab	1.05a
140-140-140	33.6c	114.2a	1.12a

Treatments	Days to Flowering	Plant Height (cm)	Herbage Weight (kg/plant)
Wet season planting			
Chicken dung (main plot)			
0	44.0a	94.8c	0.96c
2.3 tons/ha	40.5b	116.2b	1.33b
4.7 tons/ha	38.9b	124.9a	1.59a
NPK application (subplot)			
0-0-0	46.5a	79.2c	0.77c
47-47-47	42.9ab	118.5b	1.20b
93-93-93	37.7bc	125.9a	1.45a
140-140-140	36.6c	124.6ab	1.40a

Mean separation within columns per factor by LSD, 5%; Source: Acedo and Benitez, 2019.

(Blatt, 1991; Edwards et al., 2004; Gierth et al., 2005; Chassy et al., 2006). Moreover, the results from the wet season planting showed the plants taking longer time to flower and having higher plant height and herbage yield than that from the dry season crop. The lower photosynthetic light incidence and more frequent rains during the wet season may have promoted vegetative growth.

Fruit Yield

Marketable fruit yield remarkably increased in response to CD and NPK fertilization alone or in combination in the dry season planting (Table 5). With 2.3-4.7 tons CD/ha alone, fruit yields almost doubled from fertilizer-free yield of 15 kg/plot. With inorganic NPK fertilizer alone, marketable yields increased with increasing rates of application by more than two to three fold. Further increases in fruit yields occurred with combined CD and NPK application. The optimum rate appeared to be the combined application of 4.7 tons CD/ha and 93-93-93 whose yield of 57.7 kg/plot was statistically comparable to the highest yield produced among all treatments (63.8 kg/plot from combined 4.7 tons CD/ha and 140-140-140) and the highest yield when 2.3 tons CD/ha was used in combination with 140-140-140 (55.3 kg/plot). Fruit yields per hectare basis used the marketable fruit yield per plot; thus, the yield values and statistical differences followed the same trend as that of the latter (Table 5). The optimum treatment of combined 4.7 tons CD/ha and 93-93-93 yielded 28.9 tons/ha. Non-marketable fruit yield due mainly to size and shape defects did not vary with treatments and ranged from 2.4-4.0 kg/plot (Table 5).

Table 5. Fruit yield of tomato in response to fertilizer treatment (interaction effect) during dry and wet season plantings.

Treatments	Marketable Yield (kg/plot)	Non-marketable Yield (kg/plot)	Yield/ha (tons)
Dry season planting			
0 chicken dung (CD)			
0-0-0	15.0h	2.4a	7.5h

Treatments	Marketable Yield (kg/plot)	Non-marketable Yield (kg/plot)	Yield/ha (tons)
47-47-47	34.6fg	3.2a	17.3fg
93-93-93	40.0ef	3.0a	20.0ef
140-140-140	45.2de	2.8a	22.6de
2.3 tons/ha CD			
0-0-0	28.9g	2.9a	14.5g
47-47-47	46.9de	3.5a	23.5de
93-93-93	49.2bcd	2.5a	24.6bcd
140-140-140	55.3bc	3.1a	27.7bc
4.7 tons/ha CD			
0-0-0	27.5g	2.9a	13.8g
47-47-47	45.4de	4.0a	22.7de
93-93-93	57.7ab	3.6a	28.9ab
140-140-140	63.8a	3.3a	31.9a
Wet season planting			
0 chicken dung (CD)			
0-0-0	8.4g	3.7a	4.2g
47-47-47	19.3ef	4.4a	9.7ef
93-93-93	22.2de	4.1a	11.1de
140-140-140	21.5de	4.0a	10.8de
2.3 tons/ha CD			
0-0-0	15.6fg	4.9a	7.8fg
47-47-47	24.3c	4.5a	12.2c
93-93-93	30.8a	5.6a	15.4a
140-140-140	29.5ab	3.3a	14.8ab
4.7 tons/ha CD			
0-0-0	14.9fg	3.1a	7.5fg
47-47-47	23.3cd	5.5a	11.7cd
93-93-93	24.8bc	6.2a	12.4bc
140-140-140	33.6a	5.0a	16.8a

Mean separation within columns per planting season by LSD, 5%; Source: Acedo and Benitez, 2019.

In the wet season planting, marketable yield in kg/plot and tons/ha increased with increasing rates of CD and NPK application (Table 5). Optimum rate for yield increase appeared to be the combined application of 2.3 tons CD/ha and 93-93-93 increasing the yield to 30.8 kg/plot or 15.4 tons/ha or more than three times the yield without CD and NPK fertilizer (8.4 kg/plot or 4.2 tons/ha). Higher fertilizer rates did not further increase fruit yield significantly. Non-marketable yield due to fruit size and shape defects and disease symptoms (e.g. black spots, blossom end rot) did not significantly vary with treatment and ranged from 3.1-6.2 kg/plot (Table 5).

The results in the dry season cropping show that combined organic and inorganic fertilizer application was more effective in increasing tomato fruit yields as compared to when they were applied singly. This is consistent with earlier findings in which significant increases in crop yields were obtained when a combination of organic and inorganic fertilizers was applied compared with single application of organic or inorganic fertilizer (Palm, 1995; Kaur et al., 2005). The better yield of plants applied with NPK fertilizer alone compared to that of CD alone was anticipated. Inorganic fertilizers contained soluble, readily available nutrients for plant use to produce higher yields (Chassy et al., 2006). In contrast, organic fertilizers like CD have low nutrient levels and slow rate of mineralization to release nutrients for plant uptake (Blatt, 1991).

There were similarities and differences in yield response of the wet and dry season crop. Optimum rate of fertilizer application differed, 2.3 tons CD/ha and 93-93-93 producing a yield of 30.8 kg/plot or 15.4 tons/ha in the wet season while that during the dry season, 4.7 tons CD/ha and 93-93-93 producing a much higher yield of 57.7 kg/plot or 28.9 tons/ha. Furthermore, non-marketable fruit yield differed as it was higher in the wet season (3.1-6.2 kg/plot) than in dry season (2.4-4.0 kg/plot). During the wet season, the wet, humid and cloudy environment may have favored vegetative growth and disease development at the expense of fruit production. As shown earlier, the vegetative parameters were higher in the wet season than in the dry season.

Fruit Quality

Fruit size did not significantly differ with treatment in both dry and wet season cropping (Table 6). Fruit length and width ranged from 35-39 cm and 24-30 cm in the dry season, and from 35-39 cm and 26-29 cm in the wet season, respectively. However, fruit weight significantly increased with increasing rate of CD application while NPK rates at 93-93-93 in the dry season planting and 47-47-47 in the wet season planting were sufficient to increase fruit weight (Table 6). TSS also increased with CD and NPK application in the dry season planting, with the lowest rate of application (2.3 tons CD/ha; 47-47-47) being enough to bring this effect (Table 6). TA did not significantly vary with treatment and ranged from 0.20-0.24% (Table 6). In the wet season planting, TSS and TA contents did not differ with treatments and ranged from 5.13-5.75^{o}B and 0.17-0.23% citrate, respectively.

The insignificant effect of fertilizer treatment on fruit size in both dry and wet season crops suggests that this fruit attribute is a stable varietal trait. The increase in fruit weight with fertilizer treatment with no corresponding increase in fruit size indicates that the fertilized plants had higher rates of assimilate accumulation in the fruit compared to unfertilized plants. Supportive to this was the increase in TSS content of fruits from fertilized plants though the TSS increase in the wet season crop was not statistically significant. Previous studies have shown that tomatoes applied with organic fertilizer in combination with inorganic fertilizer contained higher TSS compared to chemically fertilized crops (May and Gonzales, 1994; Chassy et al., 2006). On the other hand, TA is an important quality attribute that contributes to flavor of tomato products. The results of the present study showed that fertilizer treatment had no marked influence on TA content in both dry and wet season crops contrasting previous findings that organic fertilizer alone or in combination with inorganic fertilizer increased the TA content of tomato (Toor et al., 2006). Differences in variety response, soil and climate have been implicated in the variable responses of tomatoes to fertilizer application.

Fruit Shelf Life

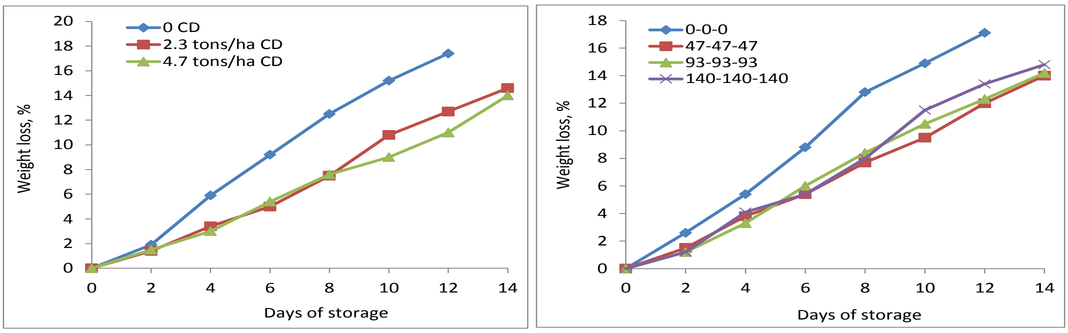
Weight loss increased with storage (Figure 1). Fruits from unfertilized plants in both dry and wet season plantings showed higher weight loss than fruits from fertilized plants. The different levels of organic and inorganic.

Table 6. Fruit quality attributes of tomato in response to fertilizer treatment during dry and wet season plantings.

Treatments	Fruit Size (mm)		Fruit Weight (g)	TSS (^{o}B)	TA (% Citrate)
	Length	Width			
Dry season planting					
Chicken dung (main plot)					
0	36.0a	26.1a	62.8c	5.65b	0.20a
2.3 tons/ha	37.2a	27.7a	70.3b	6.25a	0.23a
4.7 tons/ha	38.8a	28.9a	75.4a	6.10a	0.22a
NPK application (subplot)					
0-0-0	35.9a	24.4a	58.8c	5.39b	0.23a
47-47-47	37.2a	27.8a	69.4b	6.35a	0.21a
93-93-93	38.3a	27.9a	73.2ab	6.33a	0.21a
140-140-140	38.5a	29.3a	73.7a	6.04a	0.24a
Wet season planting					
Chicken dung (main plot)					
0	35.1a	27.6a	69.3c	5.28a	0.17a
2.3 tons/ha	37.6a	28.2a	74.8b	5.50a	0.23a
4.7 tons/ha	38.3a	28.9a	79.7a	5.75a	0.21a
NPK application (subplot)					
0-0-0	37.0a	26.7a	60.6b	5.13a	0.20a
47-47-47	38.2a	27.3a	79.0a	5.61a	0.20a
93-93-93	38.0a	28.9a	77.4a	5.44a	0.18a
140-140-140	37.8a	28.8a	80.4a	5.56a	0.19a

Mean separation within columns per factor by LSD, 5%; Source: Acedo and Benitez, 2019.

Dry Season Planting



Wet season planting

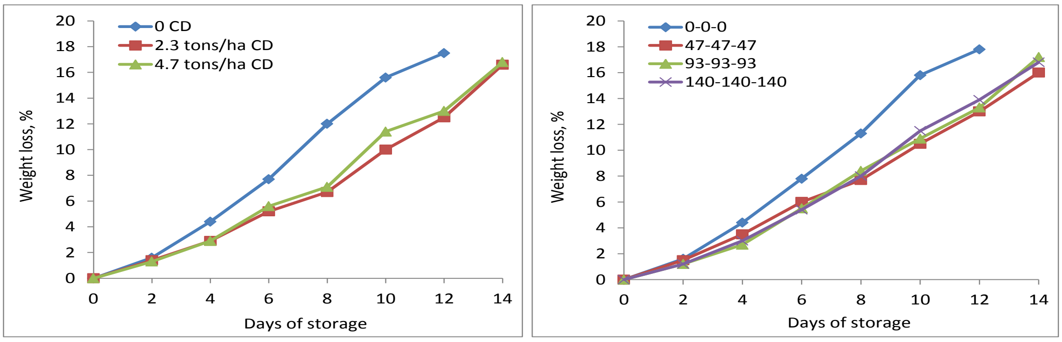
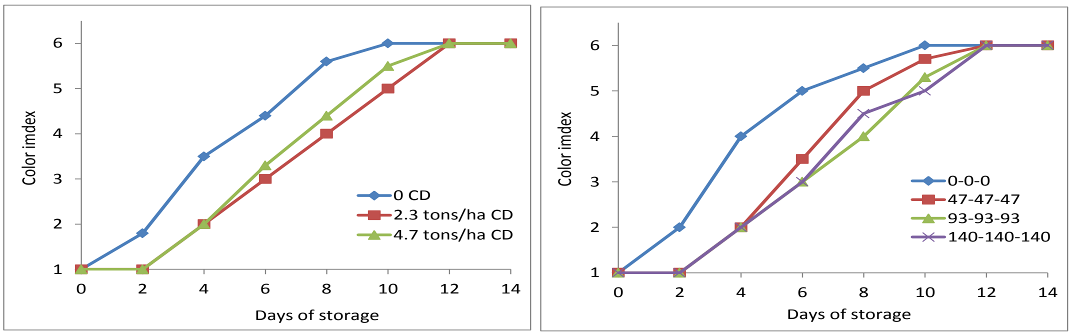


Fig. 1. Weight loss (% of initial weight) of tomato in response to fertilizer treatment during dry and wet season plantings. (Source: Acedo and Benitez, 2019).

Dry Season Planting



Wet Season Planting

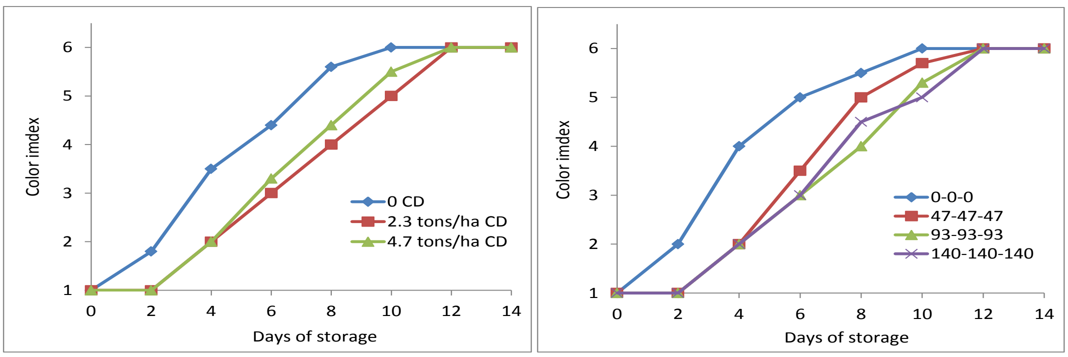


Fig. 2. Peel color development of tomato in response to fertilizer treatment during dry and wet season plantings. (Source: Acedo and Benitez, 2019)

fertilizers did not differ much in reducing weight loss. Similarly, ripening associated fruit reddening proceeded at a faster rate in fruits from unfertilized treatment than from fertilized treatments in both dry and wet season crops (Figure 2). The different levels of organic and inorganic fertilizers had similar effect in slowing fruit reddening, except that the application of 47-47-47 resulted in relatively faster rate of reddening than higher NPK rates. As a result, the ripening period (days to full red) of fertilized treatments was significantly longer than that of unfertilized treatments (Table 7). Fruits fertilized with 47-47-47 had shorter ripening period than other fertilized treatments.

As a result of ripening delay and weight loss reduction, shelf life of fruits from fertilized treatments significantly increased (Table 7). All NPK rates (47-140 NPK) with or without CD had the longest shelf life of 14 days. Without inorganic fertilizer, shelf life decreased to 12 days with 4.7 tons CD/ha treatment and to 10 days with 0-2.3 tons CD/ha.

Shelf life of tomatoes is limited by respiration and ripening. Respiration increases during ripening and decreases when the fruit turns overripe. It depletes food reserves. When food reserves increased, shelf life also increased. All fertilizer treatments apparently increased the food reserves of the fruit evidenced by their higher TSS contents than unfertilized treatment (Table 6). To some extent, transpiration (water loss) could also contribute to shelf life loss. Water loss results in fruit shriveling and accounts mainly for weight loss. All fertilized treatments had lower weight loss (Figure 1) and hence lower water loss than unfertilized treatment. Earlier studies showed that fertilizer application using organic and inorganic sources improved the postharvest life of tomatoes (Patil et al., 2004).

Table 7. Fruit ripening period and shelf life of tomato in response to fertilizer treatment during dry and wet season plantings.

Treatments	Ripening Period (Days to Full Red)	Shelf Life (Days to VQR 5)
Dry season planting		
0 chicken dung (CD)		
0-0-0	8.0c	10.0c
47-47-47	10.0b	14.0a
93-93-93	10.5ab	14.0a
140-140-140	11.0a	14.0a
2.3 tons/ha CD		
0-0-0	8.5c	10.0c
47-47-47	10.5ab	14.0a
93-93-93	11.0a	14.0a
140-140-140	11.0a	14.0a
4.7 tons/ha CD		
0-0-0	8.5c	12.0b
47-47-47	10.0b	14.0a

Treatments	Ripening Period (Days to Full Red)	Shelf Life (Days to VQR 5)
93-93-93	11.0a	14.0a
140-140-140	11.0a	14.0a
Wet season planting		
0 chicken dung (CD)		
0-0-0	8.2c	10.0c
47-47-47	10.0b	14.0a
93-93-93	10.5ab	14.0a
140-140-140	10.2ab	14.0a
2.3 tons/ha CD		
0-0-0	8.5c	10.0c
47-47-47	11.0a	14.0a
93-93-93	10.5ab	14.0a
140-140-140	11.0a	14.0a
4.7 tons/ha CD		
0-0-0	8.5c	12.0b
47-47-47	10.0b	14.0a
93-93-93	11.0a	14.0a
140-140-140	11.0a	14.0a

Mean separation within columns per planting season by LSD, 5%; Source: Acedo and Benitez, 2019.

Economics of Optimum Fertilization

The application of CD and NPK fertilizer enhanced vegetative and reproductive development, increased fruit yields, and improved fruit quality and shelf life of tomato. The optimum rate of application was 4.7 tons CD/ha + 93-93-93 for dry season planting and 2.3 tons CD/ha + 93-93-93 for wet season planting, yielding 28.9 tons/ha and 15.4 tons/ha, respectively. The economic return of applying these optimum fertilization rates can be estimated by taking the total cost of production of about Philippine Peso (PHP) 172,575 per hectare (USD 3,451.5/ha) excluding fertilizer cost, the cost of fertilizer (added cost of the technology) and the three indicators of profitability - gross return, net return and net profit-cost ratio (PSA, 2019). Gross return is the gross value of production calculated by multiplying the marketable yield by the farmgate or producer price. Farmgate price varied with planting season and is usually lower during the dry season at about PHP 15/kg (USD 0.3/kg) due to higher market supply than during the wet season at PHP 25/kg (USD 0.5/kg). Net return or net profit is derived by subtracting total costs from the gross return. Net profit-cost ratio is the rate of return to farmers or the amount earned for every PHP spent in production. It is also referred to as benefit-cost ratio or return on investment (ROI).

Table 8 shows the costs and returns of one-hectare tomato production. Using the optimum rate of fertilizer application, net return per cropping amounted to PHP 237,835 in the dry season and PHP 193,655 in the wet season with a net profit-cost ratio of more than 1.0 which means that for every PHP invested in tomato production, over PHP 1.0 is earned. Without fertilizer application, tomato production is a losing venture, underscoring the need to apply fertilizer. The net profit realized from tomato applied with the optimum fertilization rate is about ten times higher than the net profit from the production of rice, the country's staple crop, which was estimated at PHP 22,000 per hectare (PSA, 2020). Both technical and economic aspect of a technology are essential drivers of technology adoption which can be further facilitated by the involvement of farmers in technology development.

Table 8. Cost and return of tomato production with or without optimum fertilizer application in the dry and wet season plantings.

Particulars	Production Cost, PHP			Yield (kg/ha)	Gross Return (PHP; 15-25/kg)	Net Return (PHP)	Net Profit-Cost Ratio
	-Fertilizer	+Fertilizer	Total Cost				
Dry season planting							
0-0-0	172,575	0	172,575	7,500	112,500	-60,075	-0.35
4.7 tons/ha CD + 93-93-93	172,575	23,090	195,665	28,900	433,500	237,835	1.22
Wet season planting							
0-0-0	172,575	0	172,575	4,200	105,000	-67,575	-0.39
2.3 tons/ha CD + 93-93-93	172,575	18,770	191,345	15,400	385,000	193,655	1.01

CD 2.3 tons/ha = 2,300 kg = 46 bags (1 bag = 50 kg) x PHP 90/bag = PHP 4,140.

CD 4.7 tons/ha = 4,700 kg = 94 bags (1 bag = 50 kg) x PHP 90/bag = PHP 8,460.

NPK 93-93-93 = 664 kg 14-14-14/ha = 13.3 bags (1 bag = 50 kg) x PHP 1,100/bag = PHP 14,630.

Source: Acedo and Benitez, 2019.

IV. Conclusion

Organic-inorganic fertilization proved to be very effective in improving productivity and profitability of tomato production. Optimum rate of application slightly differed only between the dry and wet season planting, with the former having higher CD requirement (4.7 tons/ha) than the latter (2.3 tons/ha) but both required the same inorganic fertilizer rate of 93-93-93. The vegetable-growing area where the on-farm trials were conducted had a type IV climate characterized by more or less evenly distributed rainfall throughout the year, although it was relatively wetter during the wet season cropping resulting in lower yields than during the dry season cropping. The participatory approach pursued in this research was able to equip farmers with first-hand knowledge and skills on how to adjust and improve their farming practices particularly the fertilization practice in order to increase quality yields and farm profits. Subsequent activities could measure the impact of this intervention and use the findings in future scaling and expansion initiatives.

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