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Effect of Organic/Inorganic-Cation Balanced Fertilizers on Yield and Temporal Nutrient Allocation of Tomato Fruits under Andosol Soil Conditions in Sub-Saharan Africa

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Abstract

The impact of organic fertilizers on plant behaviour under andosol conditions is not well understood. A field experiment was conducted on a silty and slightly acidic andosol, very poor in phosphorous (3 mg $kg^{-1}$of soil) and potassium (0.13 meq/100g of soil), with an imbalance Ca:Mg:K ratio of 74.0:25.0:0.7. The effect of integrated mineral fertilization (using N, P, K, Ca and Mg), dry poultry manure (organic), the association of the two (organo-mineral) fertilizers and non-integrated mineral fertilization has been studied on yield and nutrient allocation of two varieties of tomato (*Solanum lycopersicum* L. var. *Roma VF* and *Tima*). Yields of red tomatoes from organo-mineral fertilized plants (39.27-34.38 t ha^{-1}) were three times higher than the yields from plants fertilized with non-integrated minerals (12.97-11.59 t ha^{-1}). Allocation of macronutrients (P, K and Ca) was high in fruits from plants fertilized with organic, organo-mineral and integrated mineral fertilizers. Fruit calcium increased mostly at the fruit ripening stage, while phosphorus and potassium accumulated mainly before the fruit ripening stage. This trend was by far more pronounced under organo-mineral and organic fertilization. Overall, the kinetics of nutrient allocation indicate a clear positive impact of poultry manure and organo-mineral fertilizers in improving tomato production on andosol.

Keywords: *Solanum lycopersicum*, yield, nutrient accumulation, andosol, organic manure, cation balance.

1. Introduction

A correct soil nutrient balance is essential for healthy growth and high crop productivity (Tonfack et al., 2009). Fruit production is directly associated to the allocation of nutrients in sink organs. Tomatoes are strong sink organs but their production remains challenging under tropical soils developed from volcanic materials. The western region of Cameroon is partially covered by volcanic materials. Its geological substratum is constituted of a thick layer of pyroclastites on which has developed a soil classified according to the world referential basis of resources in soil, as slender andosols (FAO-ISRIC, 2006) also known as andisols or volcanic ash soils. These soils are considered to have an average to high agricultural potential (Bationo et al., 2006) and are widely cropped (Sansoulet et al., 2007). Despite the fact that yields remain low (about 18 tonnes of tomatoes per ha), tomato production has become a current practice as it contributes to poverty alleviation of smallholders' households by enhancing their income (World Vegetable Centre, 2007). Farmers are suffering from declining soil fertility and are complaining about weak responses of their

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soil fertility management. Investigations have shown that farmers mostly rely on a single option of conventional nutrient replenishment, without taking into account the soil mineral balance. This agricultural system enhances negative soil nutrient balance and weak response of non-integrated mineral fertilization (Tonfack et al., 2009).

Actually, the challenge is to reach the agro-climatically potential yield of crops, using the best available technologies and farming practices to avoid abiotic stresses (Tittonell et al., 2010; You and Johnson, 2008) and enhance nutrient accumulation in sink organs. Many scientists have pointed out the importance of organic fertilizers in highly degraded soils (Bationo and Buerker, 2001; Yamoah, 1998) and concluded that their judicious use in agriculture, in condition of scarcity of existing resources is critical for maintaining or increasing production (Keiichi et al., 2010). Poultry manure is a highly rich organic fertilizer that is easily available, cheaper, easier to apply and sustainable that could be a good strategy to sustain tomato production under tropical andosol soil conditions.

The aim of the present study was to investigate the pattern of mineral and carbohydrate allocation in tomatoes under an alternative method of organic fertilization as well as integrated inorganic fertilization management on an andosol soil condition.

2. Material and Methods

2.1. Culture Conditions and Experimental Design

An open field experiment was carried out at the research station of the Institute of Agricultural Research for Development (IRAD), Foumbot (10° 36’–10° 37’ E, 5° 29’–5° 30’ N, altitude 1100 m) Cameroon.

The seeds of two tomato varieties (*Solanum lycopersicum* L., cv. *Roma V* and *Tima* adapted to tropical conditions, with a medium harvest homogeneity and potential yield of 50–60 t ha^{-1}) produced by Technisem (Savigny –sur - Orge, France), were sown on September 21^{st}. Forty-days-old seedlings were transplanted in three rows (four plants per row) at 1.0 m distance between rows and 0.5 m distance within rows, into the 6.0 m^2 plots. The experimental design was a split-plot with the varieties as main plots and five different fertilizers as subplots. Each treatment had four replicates. Climatic conditions prevailing during the experimental period were registered (Table 1). In the absence of rain, plants received water by capillary rise of water from irrigation. Plants were treated twice against insects and fungi with endosulfan and mancozeb respectively.

Table 1

Climatic conditions prevailing on the experimental field, during the experiment

Month	Total precipitations (mm)	Temperature (°C)		Total sunlight (hours)
		Minimal	Maximal	
Sep	292.5	15.0	27.0	119.4
Oct	316.5	15.0	27.2	98.6
Nov	6.7	14.1	30.9	121.0
Dec	0.0	12.3	30.1	195.0
Jan 2006	46.0	14.8	29.6	188.0

Source: Meteorology section, Institute of Agronomic Research and Development of Foumbot-Cameroon, 2006.

2.2. Soil and Manure Analysis

In order to elaborate fertilization plans, soil and manure were analyzed. The andosol soil sample was collected at 15 cm depth in five different places all over the 600 m^2 experimental garden, mixed and analyzed for texture and chemical characteristics. Soils were air-dried and ground to pass through a 2 mm sieve. Soil pH in water was determined in a 1:2.5 (w/v) soil:water suspension. Organic C was determined by chromic acid digestion and spectrophotometric analysis (Heanes, 1984). Total N was determined from a wet acid digest (Buondonno et al., 1995) by colorimetric analysis (Anderson and Ingram, 1993). Exchangeable Ca, Mg, K and Na were extracted using the Mehlich procedure and determined by atomic absorption spectrophotometry. Available P was extracted by the Bray-1 procedure and analyzed using the molybdate blue procedure described by Murphy and Riley (1962). Seven months old poultry manure was collected from a local farmer and analyzed for chemical characteristics as follows: cations (Ca, Mg and K) were extracted by dry ashing in a muffle furnace at 500°C, diluted using aqua regia (acid mix of HCl/HNO_3) and analyzed using an atomic absorption spectrophotometer. Phosphorus was extracted by dry ashing and analyzed by colorimetry (Murphy and Riley, 1962). Data are reported as a percentage of dry matter. Total N was determined from a wet acid digest (Buondonno et al., 1995) by colorimetric analysis (Anderson and Ingram, 1993).The soil was loamy sand and slightly acidic. Soil apparent density was also very low, revealing a very porous soil and high organic matter content. Organic matter and nitrogen content were high, with a good potential for nitrogen mineralization. On the other hand, available phosphorous content was particularly low (3 mg P per kg of soil) and the soil was also very poor in potassium (0.13 meq/100g of soil). Exchangeable cation values revealed that the soil was profoundly unbalanced with excess of magnesium and insufficient levels of potassium [(Ca:Mg:K) = (74.0:25.0:0.7)]. Poultry manure was slightly alkaline and rich in macronutrients with very high content of cations. The [C:N] ratio was 9.3, revealing high nitrogen content and a good capacity for mineralization (Table 2).

2.3. Fertilization Treatments

Five different treatments were applied:

- F0: unfertilized soil;
- F1: integrated mineral fertilizer (IMF) providing 94 g N, 4 g P_2O_5, 20.1 g K_2O, 12.5 g CaO and 1.6 g MgO per plant. These different mineral doses were calculated with respect to tomato plants' demand for a maximal fruit output of 50–60 t ha^{-1} in tropical region (Caburet et al., 2002). This contributed to a soil final Ca:Mg:K ratio of 75.2:18.0:5.8. This fertilizer was fractionated in three applications: 50% N, 80% K_2O, 100% P_2O_5, 100% MgO and 84% CaO were applied 1 week before transplanting; then 25% N, 10% K_2O and 8% CaO were applied 2 and 4 weeks after transplanting;
- F2: poultry manure as organic fertilizer (OF) was applied 2 weeks before transplanting at 2 kg $plant^{-1}$ and completely mixed with soil, contributing to a Ca:Mg:K ratio of 68:24:7;
- F3: organo-mineral fertilizer (OMF) consisted of the F1 and F2 on the same plots;
- F4: non-integrated mineral fertilizer (NMF) providing 6 g N, 3 g P_2O_5 and 3 g K_2O per plant was applied 1 week after transplanting and completed 3 weeks later with 2.5 g N $plant^{-1}$ as practiced by local farmers.

Table 2

Properties of poultry manure and andosol

ANDOSOL			**POULTRY MANURE**		
Parameters	**Units**	**Values**	**Parameters**	**Units**	**Values**
Density	Kg/dm^3	0.74	$pH\text{-}H_2O$	units	8.77
Sand	%	50.68	Organic C	%	22.17
Clay	%	20.32	Total N	%	2.379
Loam	%	29	C/N	%	9.319
$pH\text{-}H_2O$	units	6.24	Ca^{2+}	%	1.26
Organic matter	%	9.04	K^+	%	3.223
Total C	%	5.02	Na^+	%	0.365
N	%	0.4	Mg^{2+}	%	0.527
C/N	/	12.66	P	%	2.532
Ca^{2+}	meq/100g	14.66	DW	%	74.89
K^+	meq/100g	0.13			
Na^+	meq/100g	1.51			
Mg^{2+}	meq/100g	4.93			
Bray P	ppm	3.05			
SEB	(meq/100g)	21.23			

The values are means of five soil samples randomly taken from the experimental field and three measurements of seven months old poultry manure.

Table 3

Fruit mean weight and dry matter content of tomatoes at the different developmental stages

Treatments		**Fruit mean weight (g)**			**Dry matter (%)**		
Variety	**Fertilizer**	**IMG**	**MG**	**RR**	**IMG**	**MG**	**RR**
Roma VF	control	4.83 a	19.69 a	43.21 a	5.66 a	5.44	3.71
	Integrated mineral	18.16 bc	35.93 b	50.81 a	6.08 ab	4.11	4.44
	Organic	17.83 bc	51.43 c	51.96 a	6.73 ab	4.25	3.91
	Organic-mineral	19.08 c	50.84 c	51.38 a	6.14 ab	4.80	4.34
	Non-integrated mineral	13.40 bc	37.90 b	47.04 a	7.46 b	4.71	5.03
Tima	control	10.75 b	41.23 b	63.37 b	6.21 ab	4.55	4.38
	Integrated mineral	16.09 bc	53.01 c	68.27 b	6.86 ab	5.38	3.36
	Organic	27.16 d	70.45 e	92.59 c	6.88 ab	3.99	4.21
	Organic-mineral	23.10 d	64.19 de	60.67 b	6.68 ab	4.14	4.10
	Non-integrated mineral	21.05 cd	58.25 cd	84.97 c	6.46 ab	4.01	4.32
Interaction		* (= 0.030)	ns (= 0.919)	* (=0.039)	ns (=0.127)	* (=0.021)	ns (=0.328)
Variety		‡ (<0.0001)	‡ (<0.0001)	‡ (<0.0001)	ns (=0.359)	ns (=0.239)	ns (=0.468)
Fertilizer		‡ (<0.0001)	‡ (<0.0001)	ns (=0.06)	*(=0.049)	ns (=0.101)	ns (=0.503)

Means within the column followed by different letter differed significantly by LSD (Student Newman-Keuls test at p<0.05);

*, †, ‡: significant at 0.05, 0.01 and 0.001 probability level; ns: not significant; IMG: immature green; MG: mature green; RR: red ripe.

2.4. Fruit Sampling, Sugar and Mineral Analysis

Sampling took place on a daily basis and was performed randomly from the third trusses of four plants. Fruits were tagged at setting (diameter 2 mm). Tagged fruits were collected at immature green (IMG), mature green (MG) and red ripe (RR). These stages corresponded to 45-50, 60-65 and 85-90 days post transplanting. Fruits were transported to the laboratory in refrigerated containers. At each developmental stage, four fruits were collected on the third truss of four different plants of the same plot, with three replications. The twelve fruits were used to determine fresh weight and then, nine of them were oven-dried at 65°C until constant weight was aquired. The dry samples were used to determine dry matter and three of them were homogenized and used for the determination of macronutrient (P, K and Ca) contents. Macronutrients were measured after dry ashing at 550°C by flame emission (K) or atomic absorption (Ca) spectrophotometry (Hanlon, 1992). P was determined using vanado molybdate colorimetry. Three fresh fruits were freezed at -20°C until used for sugar analysis. Fruits were ground, and centrifugated for 10 mn at 3500 rpm for juice extraction. Glucose and fructose concentrations were analysed using the EnzyPlus Sucrose/D-glucose/D-fructose enzymatic analysis method (Bergmeyer and Bernt, 1974). Fruits were collected at turning to red ripe stages for yield determination.

2.5. Statistical Analysis of the Data

Data were subjected to one-way and two-way ANOVA to determine significant differences between fertilization treatments and varieties, and interaction between fertilization and variety. The Student Newman-Keuls test at the 0.05% significance level was used to calculate Least Significant Differences (LSD).

3. Results

3.1. Temporal Fruit Mean Weight and Dry Matter Content

Generally, fruit mean weight increased between IMG and RR stages in all plots (Table 3). From the

IMG to the MG stage, the fruit mean weight multiplied 2 to 3 times while between the MG and the RR stages, fruit mean weights increased slightly. Greater differences between fertilization treatments were found at IMG ($p < 0.0001$) and MG stages ($p<0.0001$). At MG, greater fruit mean weights were observed on plants (var. '*Roma VF'* and '*Tima'*) fertilized with OF (51.43 and 70.45 g), OMF (50.84 and 64.19 g) and IMF (35.93 and 53.01 g). At RR stage, there was a significant difference between fertilization treatments for fruit mean weight, and the higher mean weights were observed on variety "*Tima*" (60.67-92.59 g).

Fruit dry matter was higher at IMG stage (5.66-7.46%) and decreased at MG (3.99-5.44%) and RR stages (3.36-5.03%) (Table 3). At IMG stage, fruit dry matter was significantly different ($p= 0.049$) between the fertilizers, while at MG stage, the difference was observed for interaction variety-fertilizer ($p= 0.039$). At RR stage, there was no difference between treatments.

3.2. Yield

In terms of the number of fruits per plant and total yield results, the differences were highly significant between fertilizers ($p<0.0001$) (Figure 1). The number of tomatoes '*Roma VF'* per plant was also highly superior to that of '*Tima'*. As compared to NMF, OF and OMF highly improved the number of fruits per plant and the yield of the two varieties. The rates of increase of the number of fruit per plant in organic plots were 159% and 127% when compared to NMF, for *Roma VF* and *Tima* respectively. In OMF plots, the rates of increase of the number of fruits per plant were 176% and 191% compared to NMF for *Roma VF* and *Tima* respectively. The rate of increase of the yield by IMF was 112% and 39% respectively for the varieties *Roma VF* and *Tima*, compared to NMF. The yields obtained with OF (34.6-33.5 t ha^{-1}) were not statistically different from that obtained with OMF (39.2-34.4 t ha^{-1}). Compared to NMF, OF induced increase yield rates of 168% and 189% in tomatoes *Roma VF* that of *Tima* respectively.

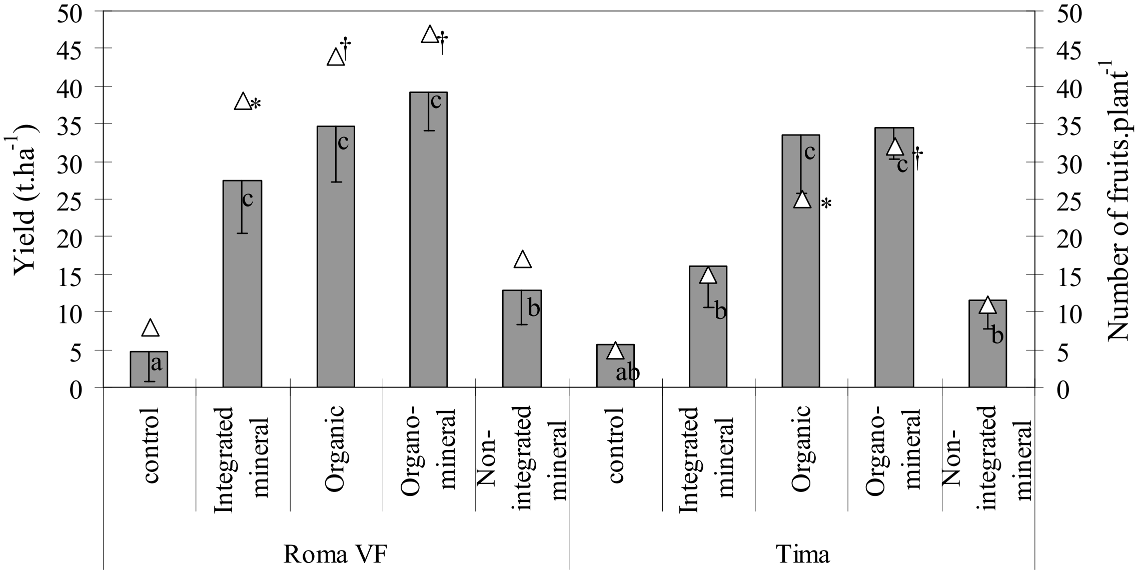

Figure 1: Number of fruits per plant and total yield of tomatoes collected at mature green or turning.

Grey bars represent tomato yields while white triangles represent the number of fruits per plant.
*, †: Values were significantly different to Non-integrated mineral value at 0.05 and 0.01 probability levels.
Bars bearing different letters are significantly different by LSD (Student Newman-Keuls test at $p<0.05$).

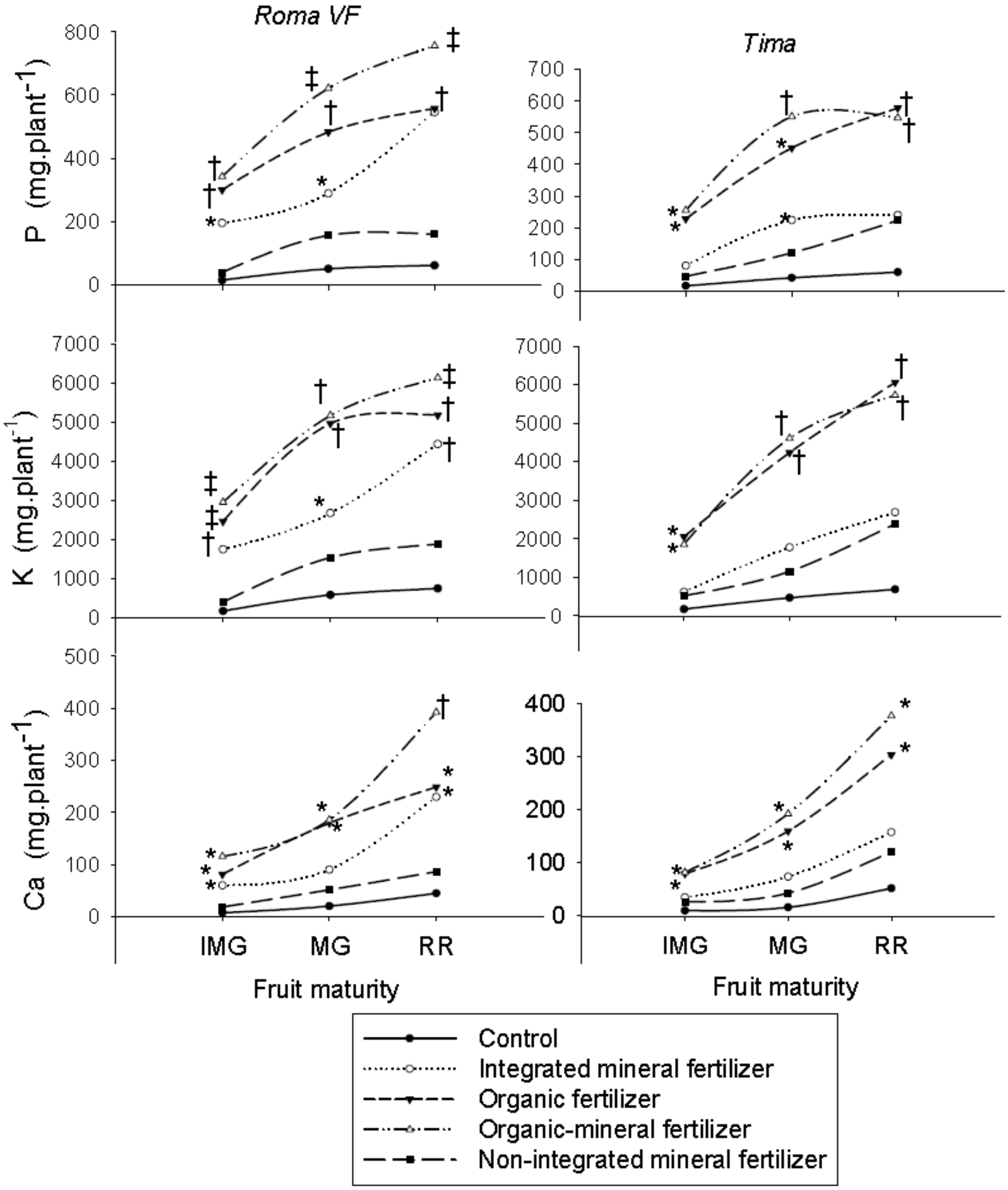

Figure 2: Macronutrient accumulation in tomatoes at different stages of fruit maturity.

IMG: immature green; MG: mature green; RR: red ripe. *, †, ‡: At each stage of fruit maturity, value of the treatment was significantly different to Non-integrated mineral value at 0.05, 0.01 and 0.001 probability levels.

3.3. Temporal Accumulation of Nutrients in Fruit

Phosphorus accumulation increased during tomato fruits' development, but the increase depended on variety and fertilizer (Figure 2). At all stages of tomato fruits' development, P was more accumulated in tomato fruits cultivated with OF and OMF. During the early phase of tomato development, plants fertilized with OF and OMF accumulated significantly more phosphorous than other fertilizers, reaching 300-342 mg.plant^{-1} for *Roma VF* and 227-254 mg.plant^{-1} for *Tima* at IMG stage. At RR stage, the total quantity of P accumulated in Tima fruits increased more than three times when plants were fertilized with OF, reaching a value of 737.87 mg.plant^{-1}.

The time course of K accumulation in tomato fruits depended on varieties and fertilization (Figure 2). Plants fertilized with OF and OMF each accumulated more K than plants submitted to other fertilizers. K accumulation in the fruits of Roma VF was higher during fruit maturation. At MG stage, tomato plants fertilized with OF and OMF accumulated 4963 and 5168 mg of K respectively in their fruits. At RR stage, the quantity of K accumulated (4776 and 6133 mg plant^{-1}) was not different from that accumulated at MG stage. In var. *Tima*, K accumulation increased continuously throughout the period of fruit development. In plots fertilized with IMF, OF and OMF, plants respectively accumulated 1771, 4232 and 4608 mg K plant^{-1}. At RR stage, these values increased to 2682, 6259 and 5274 mg plant^{-1} respectively.

For all fertilization treatments, Ca accumulation in tomato fruits was higher during the last 25 days of fruit development (Figure 2). Tomato plants accumulated more Ca when fertilized with OF and OMF. At MG stage, plants fertilized with OF and OMF accumulated 179 mg of Ca plant^{-1} for *Roma VF* and 185 mg of Ca plant^{-1} for *Tima*. At RR stage, Ca accumulated by plants fertilized with OF and OMF increased to 248 mg of Ca plant^{-1} for *Roma FV* and 392 mg of Ca plant^{-1} for *Tima*. The kinetic of Ca accumulation showed a rise during the last 25 days of fruit development.

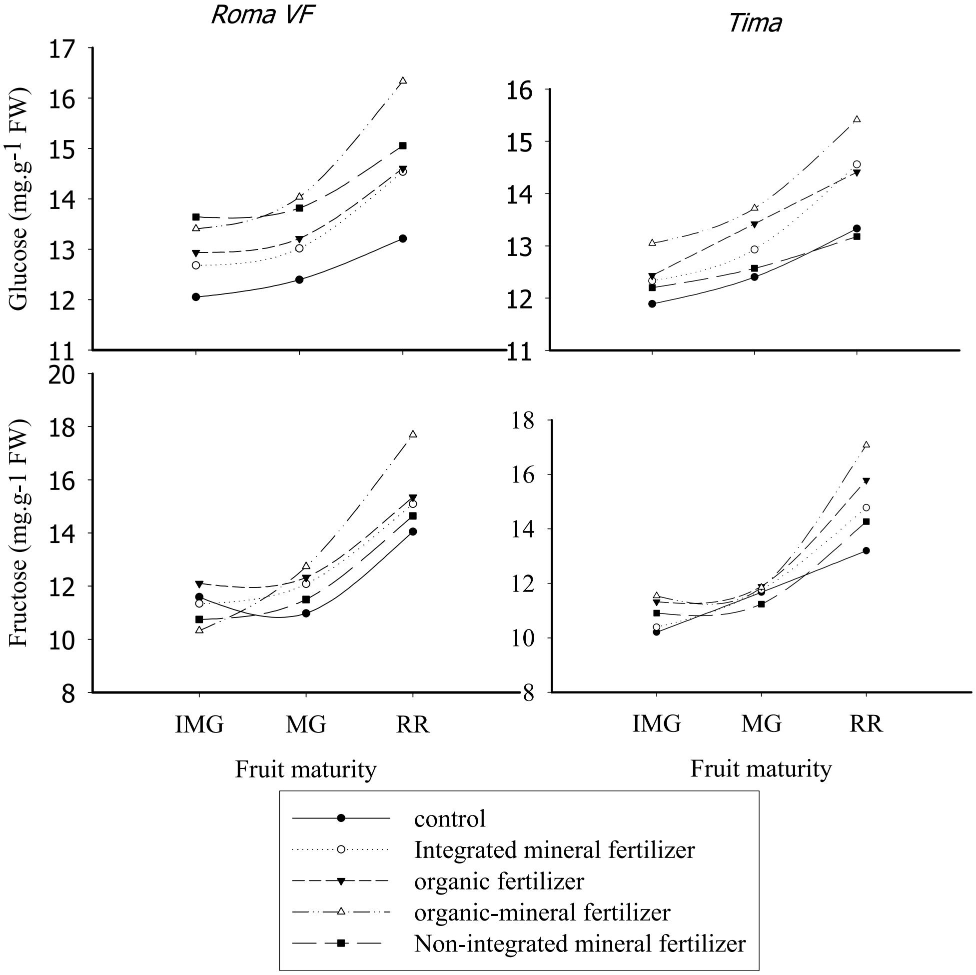

Figure 3: Time-course variation of glucose and fructose concentrations in tomatoes.
IMG: immature green; MG: mature green; RR: red ripe.

3.4. Temporal Fruit Sugar Contents

The concentrations of glucose and fructose in tomatoes increased significantly during fruit development in all varieties (Figure 3). Glucose and fructose concentrations increased most between the MG and the RR stages. Fertilizations induced a slight increase of fruit glucose and fructose concentrations at all stages of fruits development and the tomatoes produced with OMF had the highest glucose and fructose concentrations at RR stage. However, tomatoes produced with OF had their sugar content slightly inferior to that produced with OMF, but superior to that produced with IMF. Glucose concentration in fresh fruits harvested on plots fertilized with OMF increased from 14.03 to 16.33 mg g^{-1} FW for *Roma V* and from 13.71 to 15.41 mg g^{-1} FW for *Tima* while fructose concentrations moved from 12.73 to 17.69 mg g^{-1} FW for *Roma VF* and from 11.85 to 17.07 mg g^{-1} FW for *Tima*.

4. Discussion

In this experiment, the kinetics of tomato fruits nutrient accumulation varied as a function of variety and fertilization under an andosol soil condition in sub-Saharan Africa. At early stages of fruit development, there were highly significant effects of fertilization and variety on fruit mean weight and dry matter but there were no significant effect of fertilizer on fruit mean weight and fruit dry matter content at RR stage. Thus fertilization affected the speed of fruit loading, but not the final fruit mean weight and dry matter content. Tomato fruit mean weight increased from the tender stage to the mature stage and during the same time, fruit dry matter content decreased. Tomato fruit possesses strong sink capacities and its growth is largely determined by the import of water, nutrients and assimilates brought from other parts of the plant (Van-Leperen et al., 2003). Tomato yield was significantly different between fertilization treatments but not between varieties. These differences in yield may not be induced by fruit mean weight or the quantity of nutrients accumulated in each fruit at the red ripe stage, but by the total quantity of nutrients accumulated in the fruits by the whole plant. This observation is true as the number of fruits carried per plant was highly different between fertilizers and between varieties. The number of fruits per plant was significantly higher on variety Roma VF, but the mean weight of variety Tima was significantly higher at RR stage, hence a similar yield between the 2 varieties. These varieties are equally adapted to andosol soil conditions as attested by the seed producer. OF and OMF gave significantly higher yields, indicating that organic fertilizer offered a better balanced nutrient composition in the soil.

The correct balance of mineral nutrients is essential for healthy growth and high productivity in tomato plants (Malone et al., 2002; Tonfack et al., 2009). Under andosol soil condition in sub-Saharan Africa, OF and OMF might improve nutrient availability to tomato plants. It is known that OF improves mineralization-immobilization patterns, is an energy source for microbial activities, is a precursor to soil organic matter and reduces phosphorus sorption of the soil (Palm et al., 1997). These conditions favour tomato plant vigour and setting and may influence the speed of fruit nutrient accumulation.

In this experiment, P, K and Ca accumulation pattern varied, depending on the fertilization treatment and the tomato variety. Minerals were less accumulated by tomato plants fertilized with NMF and control, while IMF, OF and OMF remarkably enhanced mineral allocation. The pattern of Ca allocation was similar to that mentioned by Tonfack et al. (2009) who worked with other varieties, and found that the rate of Ca absorption was maximal during the phase of rapid cell expansion, and Ca accumulation does not increase as much as the rate of fruit growth during the same phase. Thus, fruit Ca accumulation can reach its maximal value after the phase of rapid cell expansion.

Mineral accumulation in tomato fruits from plants fertilized with IMF was lower than that of plants fertilized with poultry manure. This may be due to the multiple roles of organic manures. In fact, organic manure proves to be very satisfactory for the nutritional needs of the horticultural crops in sub-Saharan Africa (Keiichi et al., 2010). Under tropical andosol soil condition, poultry manure applied one month before transplanting not only allows keeping soil fertility, but also improves soil structure and availability of mineral elements. Organic phosphorus in poultry manure strongly integrates the pool of soil steady organic matter and organic colloids prevent soluble phosphates from linking with soluble Fe and Al in acidic soils. Moreover, fulvic acids from poultry manure might have significant carboxyl and hydroxyl phenolic contents that form cation complexes to greater level and therefore increase phosphorus availability to plant. Ho and White, (2005) said that organic fertilizer optimizes Ca uptake by optimizing the soil mineral composition, avoiding excessive K and Mg concentrations, maintains adequate Ca concentration and prevents extreme root temperature and drying in roots environment. It can be stated that in condition of excessive Mg and poor K and P content, poultry manure restores exchangeable cation balance.

K is transported in the plant readily in the phloem while Ca appears to be virtually immobile in the phloem (Malone et al., 2002) and is transported through the plant almost entirely via the xylem (Adams and Ho, 1993). It is also thought that in tomato plant, water import via the xylem almost completely ceases approximately 25 days after anthesis (Ho et al., 1987). The restriction of water transport via the xylem may almost limit the import of calcium to the fruit (Van-Leperen et al., 2003). Results in the present experiment indicate no limiting calcium accumulation in the later phase of fruit maturation. The absence of limiting calcium accumulation may be explained by the relatively high temperature (>30°C) in the experimental area. Temperature has a considerable effect on tomato fruit maturation (Darawsheh and Bouranis, 2006) since high temperature increases absorption of water and essential element ions, probably due to a reduced resistance in water translocation.

Carbohydrate content greatly increased at the later stage of fruit development. This may be another effect of high temperature since in conditions of high temperature, plant respiration increases as a consequence of the temperature sensitivity of the enzymatically catalyzed reactions involved in respiration and of the increased ATP requirements. This induces an increase in metabolic reactions such as sucrose decomposition by fructokinase and an increase in energy demands by the plant to support the increased rate of biosynthesis, transport and protein turnover that occur at high temperature.

5. Conclusion

Accumulation of nutrients in tomatoes is affected by organic and inorganic fertilizers under andosol of sub-Saharan Africa. For integrated mineral fertilizer, cation ratio should be balanced and by fractionating and applying all essential elements during the entire period of plant growth and fruit development, one could improve the fruit mineral accumulation in tropical andosol. Since poultry manure is cheaper, widely available and easier to apply, the results of the present study clearly indicate that if OF in general and poultry manure in particular is widely adopted by local farmers and applied in andosol, tomato productions and fruit quality will be boosted.

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