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RESEARCH ARTICLE

Application of the 4R nutrient stewardship concept for growing off-season tomatoes in high tunnels

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Abstract

This study aimed to adopt the concept of 4R nutrient stewardship for growing off-season tomatoes in high tunnels. The tomato crop (Hybrid 'Sahel'), grown in high tunnels, was applied with NPK fertilizer at the rate of 80:80:90 kg ha^{-1} (after each 15, 30 and 45 days interval) for four months and its effect on tomato yield and quality parameters was investigated. Application of NPK at 15 day intervals resulted in the highest nutritional quality of fruit (NPK uptake 4.32 kg m^{-2}, total soluble solids 5.6°Brix, total acidity 0.43%, protein content 15.31%, β-carotenes 0.86 mg 100 g^{-1}, total phenolics 2.34 mg 100 g^{-1}, total flavonoids 7.14 mg 100 g^{-1}, antioxidant activity 83.77%) and improved shelf-life (~ 10 days). However, NPK application at 15 day intervals was not economical in terms of total fertilizer cost incurred and subsequent yield obtained. Application of NPK at 30 day intervals was the most economical (value-cost ratio > 9.0 PKR) among all application intervals. This study suggested that implementation of the concept of 4Rs i.e., right source, right rate, right placement and right timing of fertilizer application is an effective tool for the production of high quality off-season tomatoes in high tunnels.

Keywords: 4R nutrient stewardship, high tunnels, tomatoes, yield, off-season.

1. Introduction

The 2030 Agenda for Sustainable Development and the United Nations Decade of Action on Nutrition 2016-2025 calls on all countries and stakeholders to act together to end hunger and prevent all forms of malnutrition by 2030 (FAO, IFAD, UNICEF, WFP and WHO, 2017). Conclusively, achieving nutritious food production for all, has become the greatest challenge ever faced by humanity. The need to secure access to an appropriately nutritious diet, comprising all essential nutrients and water, coupled with a sanitary environment and adequate health services to ensure a healthy life for all household members has been defined by the Food and Agriculture Organization (FAO) of United Nations as nutrition security. Hence emphasizing the efficacy of the health component and reflecting the nutritional status of the individual or community in question (FAO, 2017). Contrary to the recent past, nutrition is being considered as an integral part of food security. Accordingly, all four dimensions of food security, viz. the availability, accessibility, utilization, and stability of both macro- and micronutrients are deemed components of food security (Hwalla *et al*., 2016). Subsequent to this, a focus on the role of small producers in the agriculture sector is an important element.

High tunnels are expanding opportunities to increase local food production in the midst of a globalized food system. High tunnel farming techniques are used to produce off-season vegetables such as tomatoes, cucumbers, chilies, sweet peppers, egg plants and gourds. High tunnels have been found to offer many advantages, including environmental modification, season extension, higher yields, quality improvement, crop protection from severe weather and the ability to achieve premium prices compared to open field production (Hemming *et al.,* 2013). Tomatoes (*Lycopersicum esculentum* Mill.) are one of the most popular and widely cultivated high tunnel vegetables. Tomatoes possess a wide range of vital compounds including water (approximately 90%), soluble and insoluble solids (5-7%), citric acid, carotenoids, phenols, flavonoids, vitamins and minerals (Pedro and Ferreira*,* 2007). Ripe tomatoes have a high content of antioxidants, lycopene and carotene, which play a possible role in the prevention of certain forms of cancer (Story *et al*., 2010). In Pakistan, tomatoes were cultivated on an area of 626,00 hectares, which produced 587,100 tons tomatoes during 2015-16. During the last two decades the area under tomato cultivation in Pakistan has been increased by 50% (MNFS & R 2016). Nonetheless, the ultimate goal is to enhance quality production of tomatoes in high tunnels while improving fertilizer use efficiency and enhancing the socio-economic status of subsistence-level growers and small land owners.

Nutrient management plays a significant role in enhancing production whether it is applied in open fields or while growing off-season vegetables. Application of nitrogen (N), phosphorus (P) and potassium (K) in the form of organic and inorganic sources at critical growth stages (right time-flowering, fruit setting and fruit development) of the tomato has been reported to enhance their growth and development. For example, N requirement of tomatoes is moderate during foliage growth, until fruit development. P is very important for vigorous growth and fruit production. Likewise, K is needed for fruit development and enlargement (Nasir *et al.*, 2016). However, the United States Department of Agriculture (USDA) together with the Fertilizer Institute promotes a specific framework called 4R nutrient stewardship (4Rs) that aims at increasing productivity and profitability for growers in both highly intensive agricultural systems and subsistence-level growers. The first 2Rs, i.e. right source and right rate are commonly followed during crop production in Pakistan. However, the other 2Rs (right time and right place) are reported to be rarely practiced by farming communities, which results in low nutrient use efficiency and low economic returns (FAO, 2017ab).

The objectives of the present study were to assess the suitable time interval (right time) for NPK application on the yield and quality parameters of F1 hybrid "Sahel" tomatoes grown in high tunnels. We hypothesized that both tomato yield and quality-related parameters (nutrient uptake, total soluble solids, total acidity, protein content, β-carotenes, total phenolics, total flavonoids and antioxidant activity) would be equally responsive to the application of NPK at the right rate and the right time of application.

2. Materials and Methods

2.1. Experimental design and study site

The experiment was conducted in a high tunnel measuring 24 × 13 m with 5 m high gothic arches fitted with a double layer of greenhouse grade, ultraviolet-treated polyethylene plastic and 6ft roll-up sides at the Nuclear Institute for Food and Agriculture (NIFA) Peshawar, Pakistan (longitude 71^0 50 and latitude 34^0 01) in September 2015. The experiment was laid out in a completely randomized design (CRD) and three replications were imposed per treatment. The treatments consisted of different time intervals for the application of NPK to the tomato crop. A nursery of the hybrid tomato cultivar "Sahel" was raised in plastic tubes. After 25 days of germination, the nursery was transferred to a high tunnel. The soil of the experimental high tunnel bed was clay loamy, alkaline in nature and non-saline. The soil was marginal in terms of the contents of organic matter (OM), P, K and adequate with respect to zinc (Zn) concentration (Table 1). We maintained a distance of 1.5 and 2.5ft between plants and rows, respectively. NPK was applied at the rate of 80:80:90 kg ha^{-1} to the crop after each 15 (T1), 30 (T2) and 45 (T3) days of transplantation for four months. Based on previous related studies with high tunnel tomato production, 80:80:90 kg ha^{-1} NPK was assumed to be the right rate during the entire growth period of four months. The control treatment (T_0) was kept without any NPK application. Application of Zn to the entire field was at the rate of 5 kg ha^{-1} as a basal dose after the establishment of the crop. The experiment was properly maintained following standard cultural practices as commonly observed in high tunnel farming.

2.2. Tomato yield

Mature tomato fruits in each treatment were collected at each harvest and weighed in kilograms. The total yield per treatment was calculated by adding the yields at all harvests for the same treatment.

Table 1. Physiochemical properties of soil before transplantation

Physiochemical properties	0-15cm	16-30cm	Mean
pH	8.20	8.30	8.25
Electrical conductivity (ds m^{-1})	0.90	0.85	0.87
Organic matter (%)	0.92	0.57	0.74
Nitrogen (%)	0.069	0.058	0.06
Phosphorus (ppm)	8.12	6.25	7.18
Potassium (ppm)	150.0	130.0	140.0
Zinc (ppm)	1.40	1.00	1.20
Lime content (%)	21.75	21.25	21.50
Soil texture		………….Clay loam…………..	

2.2. Tomato yield

Mature tomato fruits in each treatment were collected at each harvest and weighed in kilograms. The total yield per treatment was calculated by adding the yields at all harvests for the same treatment.

2.3. Carpometric characteristics

Fresh ripe fruits (n=10) were randomly collected at maturity from the third harvest in each replication and evaluated for different physico-chemical parameters. The fruit weight was recorded by an electronic balance with a sensitivity of 0.01g and the fruit density was measured by the method of Jahromi *et al*., (2008). The polar and equatorial diameters of the fruits were measured with digital slide calipers (Chattopadhyay *et al*., 2013). Total soluble solids (°Brix), pH and total acidity were determined by the methods of AOAC (2016).

2.4. Chemical analysis and antioxidant activity of the tomato fruits

The protein and moisture contents of the tomato fruits were determined by standard protocols of AOAC (2016). The K and Zn concentrations of the fruits were assessed by atomic absorption spectrophotometer, P by UV-visible spectrophotometer and N by Kjeldahl apparatus (Elbadrawy and Sello, 2016). The vitamin C content of the fruits was determined by the method modified from Mahmud *et al*., (2010). The total phenolic contents and flavonoids were assessed by the methods of Luthria *et al.*, (2006). The β-carotene content was estimated by the method of Howe and Sherry (2006) and the antioxidant activity by Ahmad *et al*., (2010).

2.5. Calculation of Value-Cost Ratio (VCR)

The value-cost ratio of NPK application at different intervals of time was calculated by dividing the value of increased crop output on the total cost of fertilizer applied as presented by the following formula:

$$\text{VCR} = \frac{\textit{Value of increased crop output}}{\textit{Total cost of fertilizer applied}}$$

2.6. Statistical analysis

The data obtained was subjected to analysis of variance (ANOVA) according to completely randomized design (CRD) using the statistical software package Statistix version 8.1. Means were separated by least significant difference (LSD) test at 0.05% level of probability.

3. Results

The application of NPK fertilizers at different time intervals significantly (p<0.05) affected the tomato yield, fruit weight and fruit size in terms of polar and equatorial diameters, whereas no significant effect was noted on the density of the tomato fruits (Table 2). The highest marketable yield (12.21 kg m^{-2}), individual fruit weight (160.0 g) and polar and equatorial diameters (7.50 and 5.51 cm, respectively) of the fruits were recorded for T_2 where NPK at the rate of 80:80:90 kg ha^{-1} was applied after each 30 days of transplantation during the cropping period. The fruit density and moisture

Table 2. Effect of time interval of NPK application on the yield, density, moisture, chlorophyll content and shelf life of tomato under high tunnel cropping system

Treatments*	Yield (Kg m^{-2})	Fruit weight (g)	Density (g cm^{-3})	Moisture (%)	Chlorophyll (SPAD value)	Shelf life (Days)
T_0	3.78d	50.0d	0.98a	94.60a	47.28b	8.0ab
T_1	11.18b	147.0b	1.0a	92.15a	57.63a	9.0a
T_2	12.21a	160.0a	1.10a	92.65a	56.43a	9.0a
T_3	9.29c	115.0c	0.99a	93.30a	53.54a	9.0a

Values in each column followed by similar letters are not significantly different at P≤0.05. * T_0 = Control (without NPK); T1 = NPK application after each 15 days; T2 = NPK application after each 30 days; T3 = NPK application after each 45 days

content did not significantly (p>0.05) differ from the control treatment.

The data pertaining to pH, total soluble solids (TSS) and protein content indicated that variations in the application time of NPK significantly (p<0.05) influenced these parameters. However, the impact of temporal variation in NPK application was non-significant (p>0.05) on the total acidity of the tomato fruits (Table 4). The pH was found to be highest (4.50) for control treatment and lowest for T_2 (3.90). The highest total soluble solid (5.6°Brix), total acidity (0.43%) and protein content (15.31%) was observed in T_1 when the crop was supplied with NPK fertilizer at 15 day intervals after transplantation.

The mineral content of the tomato fruits and NPK uptake by tomato plants as affected by fertilizer application at different time intervals was depicted in Table 3. The highest N (2.45%), P (0.41%), K (3.40%) and Zn (23 mg kg^{-1}) content in the tomato fruits was recorded when the crop was frequently applied with NPK after each 15 day interval i.e. T_1. The mean total NPK uptake by the tomato plants was found highest in T_1 (4.32 kg m^{-1}) followed by T_2 (4.06 kg m^{-1}) whereas the control treatment (T_0) showed the lowest level (0.75 kg m^{-2}) of NPK uptake.

Table 4. Effect of time interval of NPK application on the nutritional quality and antioxidant activity of tomato under high tunnel farming system.

Treatments	pH	TSS (^{0}Brix)	Total Acidity (%)	Protein (%)	Vitamin C (mg 100g^{-1})	β-Carotene (mg 100g^{-1})	Total Phenolics (mg 100g^{-1})	Total Flavonoids (mg 100g^{-1})	Antioxidant Activity (%)
T_0	4.5a	4.8b	0.35a	9.0c	17.36c	0.53b	1.09c	4.14c	72.16b
T_1	4.8b	5.6a	0.43a	15.31a	18.61c	0.86a	2.34a	7.14a	83.77a
T_2	3.9bc	5.3a	0.41a	13.87b	24.33b	0.75a	2.2a	6.45a	83.27a
T_3	4.2ab	4.9b	0.37a	14.31ab	29.94a	0.60b	1.95b	5.35b	80.50a

Values in each column followed by similar letters are not significantly different at P≤0.05. * T_0 = Control (without NPK); T1 = NPK application after each 15 days; T2 = NPK application after each 30 days; T3 = NPK application after each 45 days

Table 3. Effect of time interval of NPK application on the N, P, K and Zn content and total NPK uptake of tomato plants under high tunnel farming system.

Treatments	Mineral contents of fruit				Mineral contents of straw				Total NPK uptake ($Kg\ m^{-2}$)
	N (%)	P (%)	K (%)	Zn (mg kg^{-1})	N (%)	P (%)	K (%)	Zn (mg kg^{-1})	
T_0	1.44c	0.20b	2.5c	21a	1.62c	0.11b	1.11c	25c	0.75d
T_1	2.45a	0.41a	3.40a	23a	1.90a	0.19a	1.31b	42.0a	4.32a
T_2	2.22b	0.37a	3.2ab	22a	1.84ab	0.20a	1.46a	34b	4.06b
T_3	2.29ab	0.36a	2.7bc	22a	1.74bc	0.18a	1.20bc	38ab	2.82c

Values in each column followed by similar letters are not significantly different at P≤0.05. $^{*}T_0$ = Control (without NPK); T1 = NPK application after each 15 days; T2 = NPK application after each 30 days; T3 = NPK application after each 45 days

The antioxidant compounds such as vitamin C (ascorbic acid), β-carotene, total phenolics and flavonoids and the antioxidant activity of the tomato fruits was also significantly (p<0.05) affected by variations in the application time of NPK after transplantation of the tomato crop (Table 4). The highest β-carotene (0.86 mg 100^{-1}g), total phenolics (2.34 mg 100^{-1}g), total flavonoids (7.14 mg 100^{-1}g) and antioxidant activity (83%) was observed for T_1 whereas vitamin C concentration was highest (29.94 mg 100^{-1}g) in fruit obtained from T_3. From the data it was observed that application of NPK fertilizer after each 15 days of time interval had a promising impact on the majority of antioxidant compounds and antioxidative activity of the tomato crop in high tunnel farming.

The moisture content of the tomato fruits ranged from 92.15 % in T_1 to 94.60% in control treatment (Table 2). However, the effect of NPK application time variation was non-significant (p>0.05) on the moisture content of the fruits. The data regarding the storage life of the fruits indicated that the longest shelf life of 10 days was exhibited by fruits from T_1 whereas the shortest shelf life (8.0 days) was recorded for the control treatment.

The value cost ratio (VCR) of NPK application to tomato F1 hybrid “Sahel” at different intervals of time in the high tunnel cropping system revealed that it ranged from 3.73 to 9.16 (Table 5). The highest VCR value was recorded for T_2 followed by T_3. VCR for all treatments was more than 2.0, showing satisfactory risk coverage against investment in the use of fertilizers. The data also indicated that NPK application after each 30 days interval proved better whereas application of NPK at 15 day intervals was not economical, as was clear from the least VCR value.

4. Discussion

4.1. Tomato yield and related parameters

Achieving nutritious food production for all is a challenging task and the ultimate objective of applying the concept of 4Rs is to improve the yield and nutritive value of the produce. The 4R approach on nutrient management is linked with various aspects of agricultural production systems and value chains (Figure 1). The 4R nutrient stewardship is an integral part of best management practices. Right source matches nutrient type to crop needs; Right rate matches the amount of nutrients to the crop need and depends on soil and water analyses and crop and soil fertility status; Right time involves making nutrients available when the crop needs them and is correlated with crop responsive growth stages; Right place encompasses keeping nutrients where crops can use them and is associated with

Table 5. The value-cost-ratio of NPK application at various time interval for growing off-season tomato in high tunnel.

Treatment	Total Yield (kg)	Gross Return (Rs)	Fertilizer Application Cost (Rs)	Net Return (Rs)	VCR
T_0	118	4720	--	4720	--
T_1	349	13960	1955	12005	3.73
T_2	381	15240	1035	14205	9.16
T_3	290	11600	725	10875	8.49

* T_0 = Control (without NPK); T1 = NPK application after each 15 days; T2 = NPK application after each 30 days; T3 = NPK application after each 45 days

using the best method which shows higher nutrient use efficiency and/or minimal loss (FAO, 2017ab). The present study evaluated the frequency and suitable NPK application time for the tomato hybrid cultivar "Sahel" under a high tunnel farming system to obtain potential yield and better quality produce during the off-season cropping of tomatoes. Significant variations existed among the fruit weights, fruit sizes, in terms of polar and equatorial diameters and yield of the tomato crop with respect to NPK application at different time intervals after transplantation. While the fruit density was not significantly influenced by the temporal variation in NPK application; the higher yield and better tomato weights and sizes were obtained when the crop was frequently fertilized at short intervals of time. These observations supported the fact that tomatoes are a high nutrient exhaustive crop and need frequent fertilizer applications (Sepat *et al*., 2012). In earlier research, it was reported that a combination of NP fertilizer at the rate of 110:120 kg ha^{-1} gave maximum yield as compared to other treatments (Balemi *et al*., 2008). Fandi *et al.,* (2010) reported that application of high level of NPK fertilizers increased tomato fruit weight which in turn gave maximum yield. Our values regarding individual fruit weight, fruit density and size are fairly in line with those reported in previous literature (Chattopadhyay *et al.,* 2013). The more frequent application of NPK fertilizer at short intervals of time considerably improved the number, size, density and yield of fruits per plant.

4.2. Temporal variation in NPK application, carpometric characteristics and protein content

Total soluble solids, pH and total acidity are the key quality attributes that contribute towards the processing and storage stability of tomatoes. Among the NPK treatments, the application at 15 day intervals resulted in the closest recommended values of these parameters in the tomato fruits. A high TSS value is desirable for improved nutritional and processing implications. Similarly, a high titratable acidity value is an important stability indicator for extended shelf life during storage. It has been reported that a minimum value of 0.40% acidity is required to suppress the growth of lactic acid-forming bacterial species like *Bacillus coagulans* in the processed tomatoes (Chattopadhyay *et al*., 2013). In addition, the acidity of the fruit also contributes towards the flavor of tomato products. Tomatoes are high acid food and thus require less drastic thermal treatments than foods classified as low acid (pH>4.6) for the eradication of spoilage microorganisms to ensure food safety. It has been suggested that pH 4.4 is the maximum desirable for safety and the optimum target pH should be 4.25 (Anthon *et al*, 2011). The previous literature reported

Figure 1. Potential linkages of 4R nutrient stewardship with different aspects of agricultural production systems and value chains. *Source: adopted from FAO (2017a,b).*

that the pH of tomato fruits ranged from 3.70 to 5.40 (Rai *et al.*, 2012) and TSS 4.9 to 5.5°Brix (Naz *et al.*, 2011). In the present study, the values of TSS (5.60%), total acidity (0.43%) and pH (4.23) achieved for NPK application at 15 day intervals are fairly in line with the values recommended in previous studies. Application of NPK at shorter intervals of time might have enhanced the absorption and translocation of various metabolites including the acids, minerals and carbohydrates, which contributed towards the acidity and TSS of the fruit. During ripening of the fruits, the carbohydrate reserves of the roots and stem are drawn upon heavily and hydrolyzed into sugars.

Adequate availability of nutrients in the soil enhances their acquisition and uptake by plants and subsequent conversion into plant metabolites. This phenomenon is specifically accelerated during the ripening stage of the tomato fruits (Sepat *et al.*, 2012).

The protein content of the tomato fruits ranged from 9.00 to 15.31% and the highest value was achieved when the crop was fertilized at 15 day intervals after transplantation until the final harvest of the crop. The values were significantly lower in the control treatment and in the crop that was fertilized at 30 day intervals. Generally, tomatoes are not a good source of protein, but hybrid cultivars containing protein up to 12% have been reported (Fuentes *et al.*, 2013). The higher content of protein in the tomato fruits, in the present study, was due to the consistent supply of nitrogen which is a key component for protein biosynthesis. Our results regarding higher protein content are fairly supported by the 'C/N balance theory'. The theory explains that when N is consistently available, plants will make compounds with high N contents such as protein. However, with a limited supply of N, plant metabolism changes more toward C-containing compounds such as starches, cellulose and ascorbic acid etc.

4.3 Dynamics of nutrient uptake and mineral concentration of tomatoes

It was observed in the present study that NPK uptake was enhanced when the crop was supplied with fertilizer at 15 day intervals followed by fertilizer application after each 30 days. This might be due to the fact that the plants needed more nutrients during the early stages of growth for the development of roots, shoots and flowering. It has been reported that N, P and K are the essential constituents of proteins, chlorophyll, xylum sap and other compounds along with their contribution in many other compounds of physiological importance in plants (Gallegos-Cedillo *et al.,* 2016). Hence, the application of NPK fertilizer at earlier growth stages along with subsequent applications at short intervals of time might be responsible for the increased synthesis of plant growth hormones, development of extensive root systems and therefore high nutrient utilization by the tomato plants (Ayeni, 2010). Likewise, tomatoes need a high amount of P at early stages of growth, but its K need is relatively constant throughout the crop cycle. However, the need for N take-up becomes more vigorous during the vegetative and fruiting stage. Thus, a frequent supply of nutrients enhanced the nutrient concentration of the tomato fruits as well as the total NPK uptake by the plant. It was observed that NPK uptake linearly decreased with extended fertilizer application times. The blooming stage of tomatoes started about 5 weeks after transplantation. From the blooming stage to harvest, more nutrients were needed which were compensated by frequent application of NPK with time. The application of adequate amounts of nutrients positively affected plant quality characteristics, improved total yield and reduced the chances of disease attacks (Hernández-Montiel *et al.,* 2017). The better uptake of nutrients such as N, P, K and Zn increased the plant development and the quantity of marketable tomato fruits (Al-Ismaily *et al.*, 2014).

4.4. Temporal variations in NPK application and antioxidant components of tomato fruits

The antioxidant components such as vitamin C, β-carotene, total phenolics and total flavonoids and the antioxidant activity of the tomato fruits were also significantly affected by NPK application based on time. β-carotene, total phenolics and flavonoids showed the highest values when the tomatoes were fertilized at 15 day intervals whereas vitamin C exhibited the highest value at 45 days fertilization. The higher concentration of these compounds in the tomato fruits, nourished with frequent NPK application, could be due to the fact that the soil contained a sufficient supply of basic nutrients for the synthesis of vital chemical compounds by the plants. The available literature reports that the concentration of antioxidant compounds in tomato fruits is significantly influenced by fertilizers (Toor *et al.*, 2006). Our results regarding similar values reported in previous literature for β-carotene, total phenolics and total flavonoids content are fairly supported by the fact that plants efficiently synthesized these compounds with a consistent and adequate availability of NPK to the crop (Toor *et al.*, 2006; Hdider *et al.*, 2013). However, a reversal pattern for vitamin C content was observed, whose production was enhanced at delayed NPK applications. The antioxidant activity of tomato fruits nourished with NPK fertilizer also significantly varied from the control treatment. However, the frequency and time interval for NPK application did not significantly affect the antioxidant activity of the tomato fruits. The antioxidant activity is determined by a large number of secondary metabolites present in tomatoes. Therefore, attention has been given to such compounds which exhibit prominent antioxidant activity and increase the nutritional characteristics of food. The present research finds supportive evidence from the study of Kotikova *et al*., (2011) who reported 83% hydrophilic antioxidant activity.

4.5. Temporal variations in NPK application, moisture content and shelf-life

The present study revealed that variation in time for NPK application did not significantly influence the moisture content of the tomato fruits. Nevertheless, the shelf life of the fruit was significantly affected. The longest shelf life of 10 days was shown by tomato fruits when the plants received NPK fertilizer after each 15 days of transplantation, whereas the shortest shelf life was exhibited by fruits obtained from control plots (8.00 days) and the plots (8.33 days) that received fertilizer after each 45 days of transplantation. Plant nutrition is one of the key pre-harvest factors that influence the post-harvest quality of tomato fruits (Nyamah *et al.*, 2012). Both the quantity and type of fertilizer used during production affects the post-harvest quality of tomato fruits. For instance, K plays a vital role in maintaining the shelf life of tomato fruits (Constan-Aguilar *et al.*, 2014). A timely supply of K during tomato production prevents yellow shoulder and enhances the color and titratable acidity of tomato fruits during storage (Hartz *et al.*, 2005). The extended period of shelf life of NPK applied tomato fruits, in our case, might be due to the consistent and timely application of K as compared to the control (Etminan *et al.*, 2004).

4.6. Value cost ratio of the tomato crop

Value cost ratio is an important criterion which is related to the economics of the commodity produced and determines the net profit for the farmer. In this study, different values of VCR were calculated with the addition of NPK fertilizer to the crop at different intervals of time. The highest VCR of 9.16 was achieved when the fertilizer was applied after each 30 days to the crop. The lowest VCR value was recorded when the fertilizer was applied to the crop after 15 day intervals indicating that unnecessary application of frequent fertilizer doses, giving a marginal yield increase, was neither economical nor profitable. It is thus beneficial to use the costly fertilizer inputs at judicious levels to earn more profit.

5. Conclusions

The application of NPK at the rate of 80:80:90 kg ha^{-1} to F1 hybrid "Sahel" tomatoes in high tunnels at 15 day intervals during off-season production, resulted in the highest nutritional quality of fruit and improved shelf-life. However, 15 days interval application of NPK was not economical in terms of total fertilizer cost incurred and subsequent yield obtained. NPK application at 30 day intervals was found to be the most economical. Further studies are required on a range of soils in experimental high tunnel beds in order to improve our understanding of how the application of NPK at different rates of nutrients relates to the fertility status of the high tunnel beds and how it affects the response of tomato plants in terms of production, quality and economics.

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