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Research Article

Growth and Yield Responses of Leafy Vegetables Grown in Organic and Conventional Agriculture Systems

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Abstract: Several scientific reports indicate lower as well as higher relative yield stability in organic and conventional (chemical) agriculture systems. This study presents the results of on-farm trials conducted on leafy vegetables grown in organic and conventional management systems. Four leafy vegetables collard green (*Brassica oleracea* cv. acephala), kale (*Brassica oleracea* cv. sabellica), lettuce (*Lactuca sativa*) and swiss chard (*Beta vulgaris* L. cv. cicla) were grown in organic and conventionally managed plots in the spring 2018 and 2020. United States Department of Agriculture (USDA), National Organic Program (NOP) standards were followed for cultural and management practices in organically managed experimental field plots. Synthetic chemical fertilizer was applied in the experimental field plots managed in the conventional production system. Data on plant height, leaf number and total fresh weight of leafy vegetables were measured at the end of the experiment. There was no difference in plant height and number of leaf count between the two production systems for all four crops. Collard was the tallest in the organic system in both years, kale in 2018 and collard in 2020 were tallest in the conventional system while lettuce was the shortest in both the production systems. In terms of leaf number, organic kale had the highest leaf number; however, all other crops have the same number of leaves. In organic production, lettuce fresh weight was significantly higher than the collard and similar to the rest of the crops. In conventional production, kale fresh weight was significantly higher followed by collard, swiss chard and lettuce. Moreover, lettuce fresh weight was significantly higher in organic than conventional system, no difference was recorded for swiss chard between two systems while collard and kale fresh weight was significantly higher in conventional than organic production. Our results suggest that the organic system can be a best choice for lettuce and conventional system is best choice for collard and kale.

Keywords: conventional agriculture; fresh weight; leafy greens; organic agriculture; yield

1. Introduction

Scientific reports suggest that organic agriculture is less or higher productive than a conventional system that heavily relies on the use of synthetic chemicals. However, knowledge on how yields are in organic versus conventional systems is not vastly available in many crops, and growers' interest to know responses on relative yields in crops grown in organic and conventional management systems [1–3]. The majority of the earlier studies as well as meta-analyses have confirmed organic yield lower than the conventional. For instance, meta-analyses have shown that organic production system produce

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19-25% lower crop yield than conventional [4–6]. Likewise, based on the data collected from 10,000 organic farmers representing 800,000 ha land, the study in the United States (US), found that organic system can produce about 80% of the conventional system [7]. Although yield is lower, it is possible that the yield gap can be compensated by the higher price of organic foods, and the cost involved in maintaining a healthy environment and good human health. These yield gaps can also be reduced by implementing effective agronomic practices, nutrient management and pest control strategies, and thus would create a more sustainable system [8,9].

Collard (*Brassica oleracea* cv. acephala), kale (*Brassica oleracea* cv. sabellica), lettuce (*Lactuca sativa*) and swiss chard (*Beta vulgaris* L. cv. cicla) are some of the most commonly grown and consumed leafy greens in the US. In the US, lettuce is grown in 15,590 hectares of certified organic land [10], while area and production for other leafy green vegetables such as kale, collard and swiss chard are not included in the United States Department of Agriculture census report. The higher demand for leafy greens is due to their positive association with trace minerals, omega fatty acids, antioxidants and vitamins A, C, K, and E, among others [11,12]. Since leafy greens are mostly consumed uncooked, consumers may like to purchase organic products if they are sufficiently produced and available locally. The information of how much yield one can produce from the organic production system compared to conventional systems would be helpful to the grower in making the decision to start organic production of leafy greens. As such, extensive comparative studies are needed. Therefore, we aim to evaluate the growth and yield responses of different leafy green vegetables grown in organic and conventional management systems.

2. Materials and Methods

2.1. Experimental Design

Field experiments were conducted in spring 2018 and 2020 at the Tennessee State University (TSU) organic and conventional research farm, Nashville, TN (Latitude 36° 10' N Longitude 86° 49' W). The organic research farm is the certified organic field and conventional production practices are followed in conventional research farm. In the organic field, during the fallow periods in the late fall, cover crops such as winter rye (*Secale cereale*) and hairy vetch (*Vicia villosa*) mixture were grown and allowed to senescence and decomposition. Chemical fertilizers were applied in conventional field. Pre-crops in the organic field were sweet potato and leafy greens (lettuce, kale, swiss chard, collard, mustard green and amaranth) in 2016, and sweet potato and leafy greens (lettuce, kale, swiss chard and collard) in 2017. The chemical field was fallow for one growing season, before it was used for the current research. The soil texture was sandy loam with a pH of 6.5 in organic and 6.0 in the conventional field. The soil carbon, total nitrogen, C: N ratios were 1.64%, 0.16% and 10.21, respectively in the organic field and 1.75%, 0.17% and 10.05, respectively in the conventional field. The mean monthly temperatures within the growing season (February to May) ranged from 50.15 °F to 75.55 ° in 2018 and 42 °F to 67.50°F in 2020. The total precipitation of the growing season was 6.68 inch and 4.39 inch in 2018 and 2020, respectively.

As one of the experimental factors, four leafy vegetables including collard (var. Champion), kale (var. Red Russian), lettuce (var. Coastal star) and swiss chard (var. Ford hook Giant) were used for this comparative study between organic and conventional management systems. Organic seeds and compost was purchased from High Mowing Organic Seeds (Vermont, USA) and Waypoint Analytical (Memphis, TN, USA), respectively for the organic production system. Seeds and chemical fertilizer for the conventional management system were purchased from Johnny Selected Seeds (Maine, USA). Seedlings were raised in a greenhouse in the spring 2018 and 2020 (February-March). Seeds of leafy vegetables were manually seeded on 11 March (2018) and on 4 February (2020) into 72-cell seedling trays (two seeds per cell) filled with an organic potting mix (Harvest organics, OMRI Listed). Seedlings were manually irrigated on alternative days to maintain the soil moisture.

Four leafy green vegetables were arranged in a completely randomized design in organic and conventional systems both in 2018 and 2020 and replicated three times. Therefore, treatments included crop (collard, kale, lettuce and swiss chard), production system (organic and conventional) and the year (2018 and 2020). Both organic and conventional fields were cultivated on 2 April (trial 2018) and 5 March (trial 2020) using a rotary tiller machine (John Deere, Franklin, TN, USA). Black plastic mulch (Hummert's International, MO, USA) of 0.5 mm thickness was laid using a mulch layer tractor attachment on 8 April (trial 2018) and on 6 March (Trial 2020) along with drip tape for irrigation (Berry Hill Irrigation Inc., VA, USA). After laying the mulch, small holes were manually made for each plant at 1 feet distance. Each plot was 55 feet long by 5 feet wide and each plot was divided into four subplots along the length, one for each of the four vegetable crops. Ten plants of each crop were planted in each subplot of 10 feet long. Leafy greens were transplanted manually on 10 April (trial 2018) and on 10 March (trial 2020) into subplots. Plants were fertilized immediately after transplanting in conventional and during transplanting (mixed in the soil) in organic management system. The calculated amount of fertilizer was applied directly around the individual plant. The rate of the compost and chemical fertilizer was calculated and applied based on required nutrients to leafy greens, nutrient composition of compost and soil test report. Tested plants were applied with NPK fertilizer of 5 g/plant and compost 100 g/plant. The composition of compost applied in the organic system was 0.46% total nitrogen, 46.8% moisture, 7.93 pH, 1580 mg/kg total phosphorus and 4290 mg/kg total potassium. Chemical fertilizer has Nitrogen (N) Phosphorus(P) and Potassium (K) of 8:2:12, respectively. Plants were irrigated on alternative days for 15 minutes using a drip irrigation system. Weeding was done manually and mechanically. No pesticides were applied in organic and conventional trials. At the commercial stage of maturity, vegetables in each plot were harvested from both organic and conventional on 21 May (trial 2018) and on 5 May (trial 2020). Plant height (inch) was measured for all plants, leaf count of kale, collard and swiss chard was counted and fresh weight of plants (g/plant) was measured.

2.2. Statistical Analysis

A three-way analysis of variance (ANOVA) test was performed to examine the main and interactive effects of the year (2018 and 2020), production system (organic and conventional) and crop type (collard, kale, lettuce and swiss chard) on plant height, leaf number and total fresh weight using PROC GLM in SAS software 9.4 (SAS Inc., Cary, NC, USA). When the interactive effects were significant, means were separated using Fisher's least significant difference (LSD) test at a significance level set at $P \leq 0.05$. When there are no three-way interactions but have lower-term interactions, means were pooled across them and presented by tables or figures.

3. Results

3.1. Plant Growth and Morphological Data

Results of ANOVA showed that there were significant interactive effects of year, production system and the crop type on plant height ($P \leq 0.05$; Table 1). In both the years collard had a significantly higher plant height compared to other crops in organic production whereas kale had significantly higher plant height in 2018 and collard had higher plant height in 2020 in conventional production system (Table 2). In both the years lettuce was the shortest in both the production systems.

There were significant interactive effects of year, production system and the crop type on leaf number ($P \leq 0.05$; Table 1). In 2018, kale grown in the organic system had the highest number of leaves (27.38) compared to other leafy greens in both the systems (Table 3). Collard and swiss chard had the same number of leaves in both production systems and in both years.

Table 1. P-values of the three-way ANOVA tests for the main and interactive effects of the year (2018 and 2020), production system (organic and conventional) and crop (collard, kale, lettuce, swiss chard) on fresh weight, plant height and leaf number. Significant treatment effects at $P \leq 0.05$ in bold letters.

Factor	*Fresh weight (g/plant)*	*Plant height (inch)*	*Leaf number*
Year (Y)	**<0.0001**	0.7456	**0.0068**
Production system (S)	**<0.0001**	0.7716	0.1148
Crop (C)	**<0.0001**	**<0.0001**	**0.0004**
Y × C	0.5001	**0.0004**	**0.0027**
Y × S	0.5596	0.3166	**0.0016**
S × C	**<0.0001**	**0.0011**	**0.0116**
Y × S × C	0.1598	**0.0017**	**<0.0001**

Note: leaf numbers were counted only for collard, kale and swiss chard.

Table 2. Mean (±standard error) plant height of leafy greens (collard, kale, lettuce, swiss chard) grown in the year (2018 and 2020) in two production systems (organic and conventional).

Year	*Production system*	*Crop*	*Plant height (inch)*
2018	Conventional	Collard	11.23±0.61fgh
		Kale	19.23±0.21a
		Lettuce	8.59±0.21h
		Swiss chard	13.17±0.63cdef
	Organic	Collard	17.12±0.38ab
		Kale	13.90±1.16cde
		Lettuce	8.60±0.51h
		Swiss chard	11.26±2.04efg
2020	Conventional	Collard	14.23±0.54cd
		Kale	12.46±1.73defg
		Lettuce	10.19±1.28gh
		Swiss chard	14.06±1.04cd
	Organic	Collard	15.11±0.56bc
		Kale	13.36±0.63cdef
		Lettuce	10.92±0.07fgh
		Swiss chard	13.96±0.19cd

Different lowercase letters in the column denote significant differences at $P \leq 0.05$.

Table 3. Mean (± standard error) leaf number of leafy greens (collard, kale, swiss chard) grown in the year (2018 and 2020) in two production systems (organic and conventional).

Year	*Production system*	*Crop*	*Leafy number*
2018	Conventional	Collard	13.14±0.70bc
		Kale	12.43±0.22bc
		Swiss chard	11.10±1.05bc
	Organic	Collard	9.29±0.68c
		Kale	27.38±3.57a
		Swiss chard	13.95±0.77b
2020	Conventional	Collard	10.84±0.63bc
		Kale	14.28±2.71b
		Swiss chard	13.17±1.61bc
	Organic	Collard	12.67±1.67bc
		Kale	10.50±0.29bc
		Swiss chard	9.94±0.31bc

Different lowercase letters in the column denote significant differences at $P \leq 0.05$.

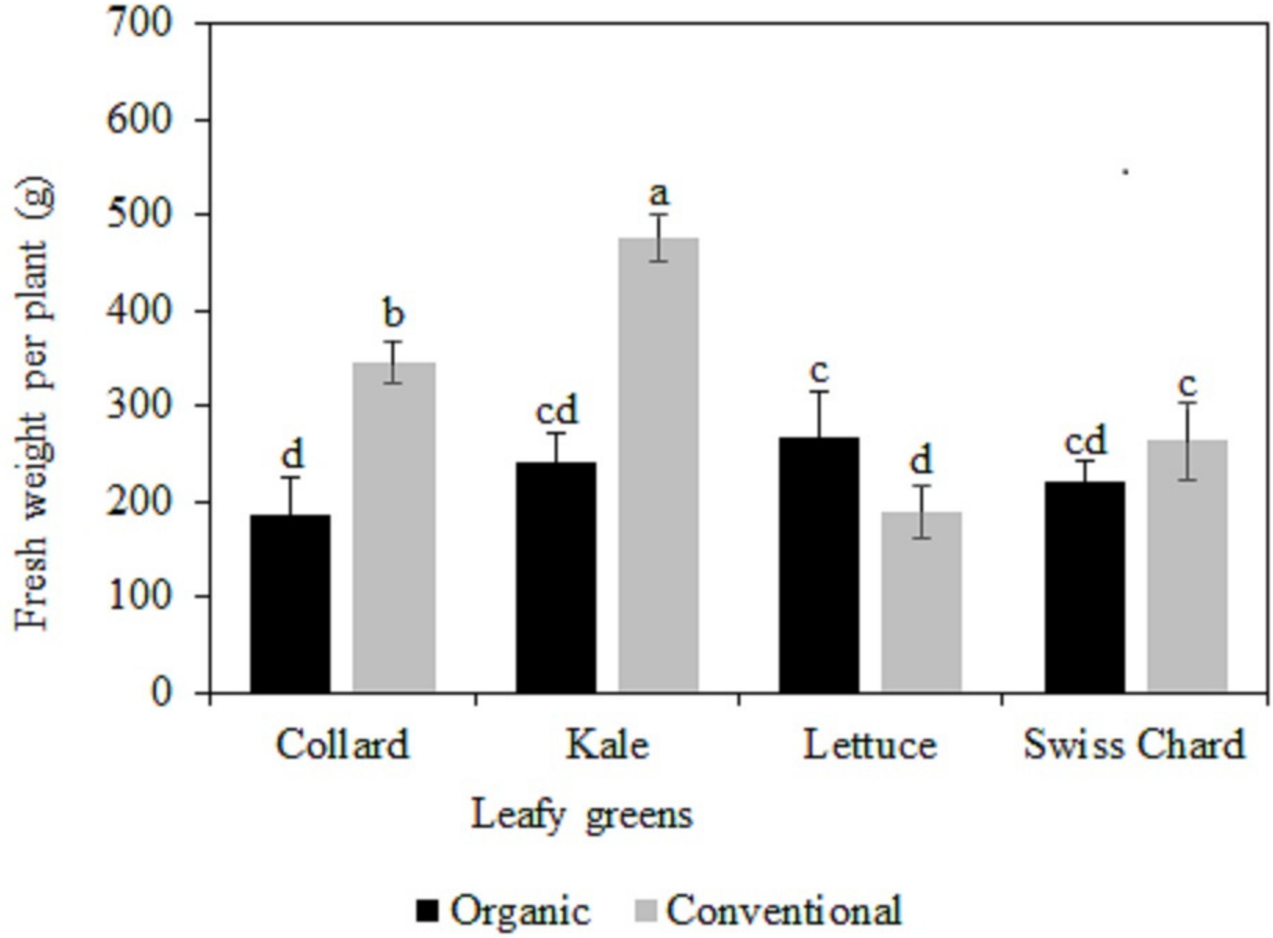

Figure 1. Mean (± standard error) of fresh weight of leafy greens (collard, kale, lettuce, swiss chard) grown under two production systems (organic and conventional) in two years (2018 and 2020).

The interactive effects of year, production system and crop type on plant fresh weight were not significant (Table 1). Plant fresh weight was significantly affected by the lower-term interaction of the production system and crop type ($P \leq 0.05$; Table 1). Moreover, plant fresh weight was significantly different between two years ($P \leq 0.05$; Table 1). The maximum fresh weight was obtained from the conventionally grown kale (475.57 g) and the lowest fresh weight was recorded for conventionally grown lettuce (189.30 g) (Figure 1). In organic production, lettuce fresh weight was significantly higher compared to collard but similar to other crops, while in conventional production, fresh weight of kale was significantly higher followed by collard, swiss chard and lettuce. Swiss chard and lettuce had similar production in the conventional system. So, in organic farming the crop with the highest market price is the best choice for growers. The fresh weight of kale and collard was significantly higher in the conventional production system, of 475.57 g and 344.08 g, respectively compared to fresh weight obtained for them from the organic system. Lettuce grown in an organic system produced significantly higher fresh weight (266.47 g) than the conventional (189.30 g). Moreover, there was no significant difference in the fresh weight between organic (221.98 g) and conventional (263.75 g) production systems for swiss chard. The maximum fresh weight was obtained in the year 2020 compared to 2018.

There were no interactive effects of year, system and crop, so means were pooled across the production system and crop. Different lowercase letters on the top of the bar denote significant differences at $P \leq 0.05$.

4. Discussion

Fresh weight of collard and kale was significantly higher in a conventionally managed field than the organic. Lettuce fresh weight was higher in the organic management field while there was no difference in fresh weight of swiss chard between organic and conventionally managed fields. Moreover, we received a significantly higher yield in the year 2020 than the year 2018. There were no differences in plant height and leaf number between two production systems. Leaf size than the leaf number and plant height was the contributing factor for higher fresh weight in the current study anticipated. Higher yield in current report in agreement with earlier reviews and meta-analyses in general that have confirmed lower crop yield in the organic management system [4–6]. The yield difference might range from 5% (rain-fed legumes and perennials on weak acidic to weak-alkaline soils) to 34% lower yields (when the conventional and organic systems are most comparable) in the organic system [4].

Since the conventional production system relies on the use of synthetic fertilizers and pesticides, plants can immediately uptake nutrients from chemical fertilizers and pest control is much easier with the use of pesticides. As a result, plants can grow faster, and thus can result in a higher crop yield. This supports higher fresh weight of kale and collard in conventional than organic production in this study. In contrast, in organic system, nutrient management and pest control are the major challenges [7]. Since organic manures are the major source of plant nutrients in the organic management system, nutrients released from manures may not meet the nutrient requirement during the high-demanding stage of crop growth [13]. Moreover, manures added in organic production need to be mineralized from organic to inorganic forms of nitrogen before they are available to plants. The microbial decomposition and mineralization of soil organic matter is a slow process and also dependent on optimum soil temperature and moisture [14,15]. As the growing period of leafy greens is rather short, nutrients from compost might not be ready to be used by plants in that short time period and low N availability from compost was made evident for lower yield [16–18]. As pesticides are restricted for use in organic production, higher yield gaps may also be associated with the crop losses in the organic management system caused by diseases, insects and weeds [4,8,18].

In contrast to the general trend, lettuce yield was significantly higher in the organic management system than the conventional and there was no difference in yield between organic and conventional production of swiss chard. Although the exact mechanism behind this response is lacking, it is possible that the nutrients released from compost are enough to gain the full potential yield of lettuce and swiss chard. A 10-year field experiment reported that crop yield response was very low in the beginning of compost application and yield increased slightly with the duration of the experiment [19]. Furthermore, we speculate that the nutrient demand for kale and collard is higher as they are heavy nutrient feeders and require large amounts of fertilizers whereas lettuce and swiss chard are medium to light feeder and thus the required nutrients might have been acquired from compost [20,21]. The nutrient availability of organic fertilizer is less initially, which limits the early growth of leafy vegetables, but if leaf picking time is extended, the growth and yield can be similar or higher than conventional system [22].

Organic system can nearly match conventional yields under certain conditions, that is, with good management practices, particular crop types and growing conditions. If compost is analyzed prior to use and provided with approximately the same amount of essential nutrients from compost as from inorganic fertilizers, the yield gap can be lower [23]. As such, growers can compensate for the little yield gap from cheaper inputs, higher and more stable prices and risk diversification [24]. Organic farmers rely on animal manures and compost and practice crop rotation, adjust the timing of planting and harvesting, the use of cover crops and natural pest control can reduce the risk in the longer term [25]. Alternatively, organic liquid fertilizers that have been developed by different manufacturers can be incorporated as an important nutrient source for short-duration crops like leafy greens. The homogeneity and the even distribution can be achieved when liquid fertilizers are applied to the soil and are easier to transport, handle and apply compared to solid fertilizers [26]. Some liquid fertilizers are evaluated during the growing season which are top-dressed and reported increased organic matter content, microorganism populations in the soil and stable soil pH [27]. Liquid fertilizer is a prerequisite to ensure optimal nutrient supply for growing crops and on the other hand to avoid environmental problems caused by over fertilization [28].

We observed a higher crop yield in 2020 than in 2018. We transplanted seedlings of leafy greens into the main field one month earlier in the year 2020 than the year 2018. Plant growth was better when planted one month earlier in 2020 likely due to the suitable temperature and lower pest attack. When crops were transplanted in April 2018, the temperature during the active crop growing period was higher than the optimum temperature requirement, thus the condition resulted in poor crop growth. Plants stressed with temperature and probably with soil moisture are at great risk of pest attack. These might be the reasons for higher crop yield in 2020 compared to 2018.

Nutrients and pest management are challenging in the organic system and also the difficulties in getting sufficient organic certified seeds, fertilizers and compost in bulk amount. Government incentive programs on organic agriculture farming and certification would help to increase area and production. Although organic agriculture is considered an environmentally friendly and sustainable alternative, there is also an argument that it would increase greenhouse gas emissions from the related land use changes [29,30]. This is especially because organic agriculture requires higher land to get the same amount of production as conventional system. Likewise, organic farmers often lay down sheets of black plastic mulch over the soil to control pests and weeds, covering huge areas of land with single-use plastic would create an enormous amount of waste material in the soil. Therefore, while adopting organic agriculture, it is important to properly manage the negative impacts that might arise on the environment and human health.

5. Conclusions

Lettuce fresh weight was higher in the organic management system and collard and kale yield was higher in the conventional production system. There was no difference in fresh weight of swiss chard between organic and conventional systems. Lettuce and swiss chard may be preferred leafy greens for organic production system though market price may have influence on the choice. Kale and collard performed well in conventional production system.

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