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Spatial Trends and Distribution Patterns of Organic Crop Production in Central Kenya

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Abstract This research adds to knowledge on trends and distribution patterns of organic agriculture (OA) systems. The study was descriptive in nature involving 329 organic farmers selected through stratified random sampling from four counties in Central Kenya. The counties were Nyeri, Murang'a, Kirinyaga, and Kiambu. A peer and expert reviewed semi-structured questionnaire and GPS devices were used for data collection. The mean acreage under OA in the four counties rose significantly from M = 264.88, (tau) τ = .0.44, p < .05 in 2012 to M = 508.95, τ = .95, p < .05 in 2017. The annual income from organic crops increased by 84% from KShs 29,926 ($299.26) in 2012 to KShs 181,635 ($1816.35) in 2017. Most of the organic farms were clustered as reported by the average neighbor index (index = .05, p <.05, Z = -37.24). More conventional agricultural farmers converted to OA, thus, acreage and income emanating from organic crop production rose tremendously. The clustering of the farms resulted from the formation of farmer groups, proximity to the packing houses and holding facilities, environmental, sociological, and financial factors. More farmers in the region should be encouraged to convert to OA. An expansion of clusters would enhance the sharing of information.

Keywords Estimated positional errors, Organic agriculture, Spatial trends, Distribution patterns

1. Introduction

Agricultural systems are continually changing worldwide in response to economic, technological and social trends (Limpisathian, 2011). FAO in its report recommended a wide range of creative, sustainable agricultural systems, which not only provide food, but also a factor in the economic value (FAO, 2016). Sustainability is a three-dimensional concept that encompasses economic, environmental, and social aspects (Mani, et al., 2016). OA is a promising path that is associated with environmental, social, and economic benefits of agriculture (Ahlem & Hammas, 2017). Few studies have been conducted in developing countries, especially sub-Saharan Africa, to map organic agriculture (OA). Empirical evidence indicates that adopters of OA are not randomly distributed across space, but are spatially clustered (Wollni & Anderson, 2014). Eades and Brown (2006) posit that the concentration of organic acreage and producers in certain regions of the U.S. seems to indicate that some form of clustering is present within the industry and that factors exist which make OA more apt to survive and grow in some regions rather than others. From a regional science point of view, organic farms appear to be under the influence of "centripetal forces" that tend to concentrate and encourage economic activity in the form of economic clusters (Eades & Brown, 2006).

OA activities are regionally agglomerated to a certain degree. Regions with high shares of organic farming tend to be close to other regions with high shares of organically farmed land (Parker & Munroe, 2007). In addition, a high share of organically managed land in a region seems to be an ideal precondition for the decision of a farmer to convert to OA organic production (Schmidtner, et al., 2012). Research shows that spatial externalities whose marginal impact decreases with distance influence the location and production patterns of certified organic farms (Lewis, Barham & Robinson, 2011; Parker & Munroe, 2004; Parker & Munroe, 2007). Vos (2000) observed that organic practices are often closely related to landscape heterogeneity and a range of social and cultural diversity partly due to the agro-ecological differences that occur from the farm-scale to the community and to the region. Bagi and Reeder (2012) also found that regional differences in OA could result from agricultural geography. Research has shown that farmers in areas with low potential for intensification are more likely to adopt organic farming since flat land and certain soil types are more conducive to intensive agriculture while steep slopes and hilly terrain are disadvantages to intensification and mechanization (Schmidtner, et al., 2012; Wollni &

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Andersson, 2014).

Environmental, social, and financial elements have been found to influence the distribution of OA systems. Bichler, Haring, Dabbert, and Lippert (2005) categorized factors with a likely influence on spatial distribution OA into four, namely, natural, farm-structure, socio-economic, and political elements. A study by Kacprzak and Mackiewicz (2014) reported that OA in Poland and Spain are determined by a number of elements including financial aid, an introduction of clear law, the scale of OA production, and demand for OA produce. A study by Gabriel, et al., (2009) described the key economic and sociological variables that influence conversion to OA as yields, profits, forces of demand and supply, and public/farmer attitudes. Research has shown that environmental conditions predispose farmers to convert from conventional to OA, thus this form of agriculture becomes clustered in the agricultural landscape. Specifically, agro-ecological conditions and locality will directly influence the possibilities of a farmer to implement and derive benefits from OA (Wollni & Andersson, 2014).

A previous study has suggested that spatial aggregation is also likely to evolve out of sociological factors (Gabriel, et al., 2009). Most farmers are likely to convert to OA in a locality where most of the farmers have already converted. Morone, Sisto, and Taylor (2006) reported that the social acceptability of organic farmers might be higher if many farmers in the vicinity are already organic. Wollni and Andersson (2014) suggested that policies that target areas with more desirable land use or encourage such land uses can potentially reduce negative spatial effects and promote OA. A study involving network analysis in Italy provided evidence that local organizations in the organic sector play a role in the diffusion of legal and technical knowledge (Morone, et al., 2006). Social acceptance has been found to play an important role in the adoption decision of farmers in developed countries. Social conformity in spatial clustering is where there is a tendency of the individual to behave in compliance with the individual's social group (Läpple & Kelley, 2015).

A few studies have been conducted to provide insights on financial factors influencing the distribution of OA. Wollni and Andersson (2014) observed that organic markets are likely to be more mature for certain crops than for others in a particular region. The market of organic products also counts, for instance, if farmers are situated in a location with conditions suitable for growth of products that command organic premiums, they will have greater financial incentives to convert to OA. Accordingly, there is a likelihood of the occurrence of spatial concentration of OA to the extent that these geographic related-factors are spatially correlated (Wollni & Andersson, 2014).

2. Purpose and Objectives

This study sought to spatially analyze and describe the trends and distribution patterns of organic crop production in Central Kenya. This research provides empirical evidence that could be beneficial to the planning and execution of extension services related to OA as well as the formulation of supportive policies, all of which could spur the growth of the organic industry in Kenya. The research objectives were to:

a) Analyze the spatial trends of organic crop production, and
b) Describe the spatial distribution patterns of organic crop production in Central Kenya

3. Materials and Methods

Data Collection

This research was conducted in Central Kenya, which covers an area of 13,191 km^2 (5,093 sq. miles) and contains a population of 4,383,743 (Kenya National Bureau of Statistics, 2010). Central Kenya is located to the north of Nairobi and west of Mt. Kenya. The study was descriptive in nature involving 329 organic farmers selected through a stratified random sampling of four counties. The counties were Nyeri, Murang'a, Kirinyaga, and Kiambu as shown in Figure 1. Agricultural production in Central Kenya is mainly rain-fed where rainfall occurs in two seasons. The long rainy season occurs between March and June, while the short rains fall between October and December. The mean annual rainfall ranges between 1200 mm to 1500 mm. The soils, which are primarily nitosols, are deep, and of moderate to high fertility (Franzel, Wambugu, & Tuwei, 2003).

Data were collected using a semi-structured questionnaire that had been reviewed by peers and experts in the area of Geographic Information System (GIS) and Agricultural Education. GPS receivers were used to collect organic farms' spatial data. The trends data covered the variety of crops, acreage, and income on a yearly basis between 2012 and 2017. Upon data collection completion, the GPS, and survey data were summarized in a comma-separated values (CSV) file and exported to a shapefile. The data were then projected using the World Geodetic Survey (WGS) 84/UTM zone 37S chosen with the altitude of the region in mind. To minimize GPS multipath errors, geographic coordinates were taken at point of the farms with no or minimal barriers so as to avoid reflection of GPS signals (Gikunda & Griffith, 2019).

Data Analysis

The analysis of the data involved three statistical programs. GeoDa was used to perform spatial autocorrelations of the organic farms, ArcMap for the average nearest neighbor (ANN) (Anselin, Kho, & Syabri, 2005), and the Mann Kendall trend test was conducted using R – program (Kendall, 1975). The test is a non-parametric test for the analysis of temporal series regardless of data distribution, and seasonality (Mattar, Sobrino, Julien, & Morales, 2011; Platnick, et al., 2003). The Mann-Kendall test involves no assumptions as preconditions for hypothesis testing and it is less affected by missing values or outliers (Kendall, 1975). It is based on the following equation (1)

$$Z = \begin{cases} \dfrac{S-1}{\sigma s}, & S = 0 \\ 0, & S = 0 \\ \dfrac{S+1}{\sigma s}, & S < 0 \end{cases} \quad (1)$$

$$S = \sum_{k=1}^{m} \sum_{j=k+1}^{m} sign\left(yj - yk\right) \quad (2)$$

$$\sigma s = \sqrt{\frac{m\left(m-1\right)\left(m-5\right)}{18}} \quad (3)$$

Where *m* is the size of the sample and (*yj*, *yk*) the values for years *j* and *k* (j > k). Equation (4) represents the Mann-Kendall statistic (*S*), and measures the trend in the data; a positive (negative) value of *S* indicates an increasing (decreasing) trend (Ning, et al., 2016; Platnick, et al., 2003). The statistic *S* is defined by the sign function, which is an indicator function with values of -1, 0 or 1, depending on whether *yj* - *yk* is less than zero, equal to zero or greater than zero, respectively (Platnick, et al., 2003). Equation (5) defines the variance of *S* (σs) when $m \geq 8$ (Kendall, 1975). Correlation is assessed through the Kendall rank correlation coefficient (tau coefficient), obtained as τ = S/D, where D is the maximum permitted value of *S*, given by:

$$D = \frac{m(m-1)}{2} \quad (4)$$

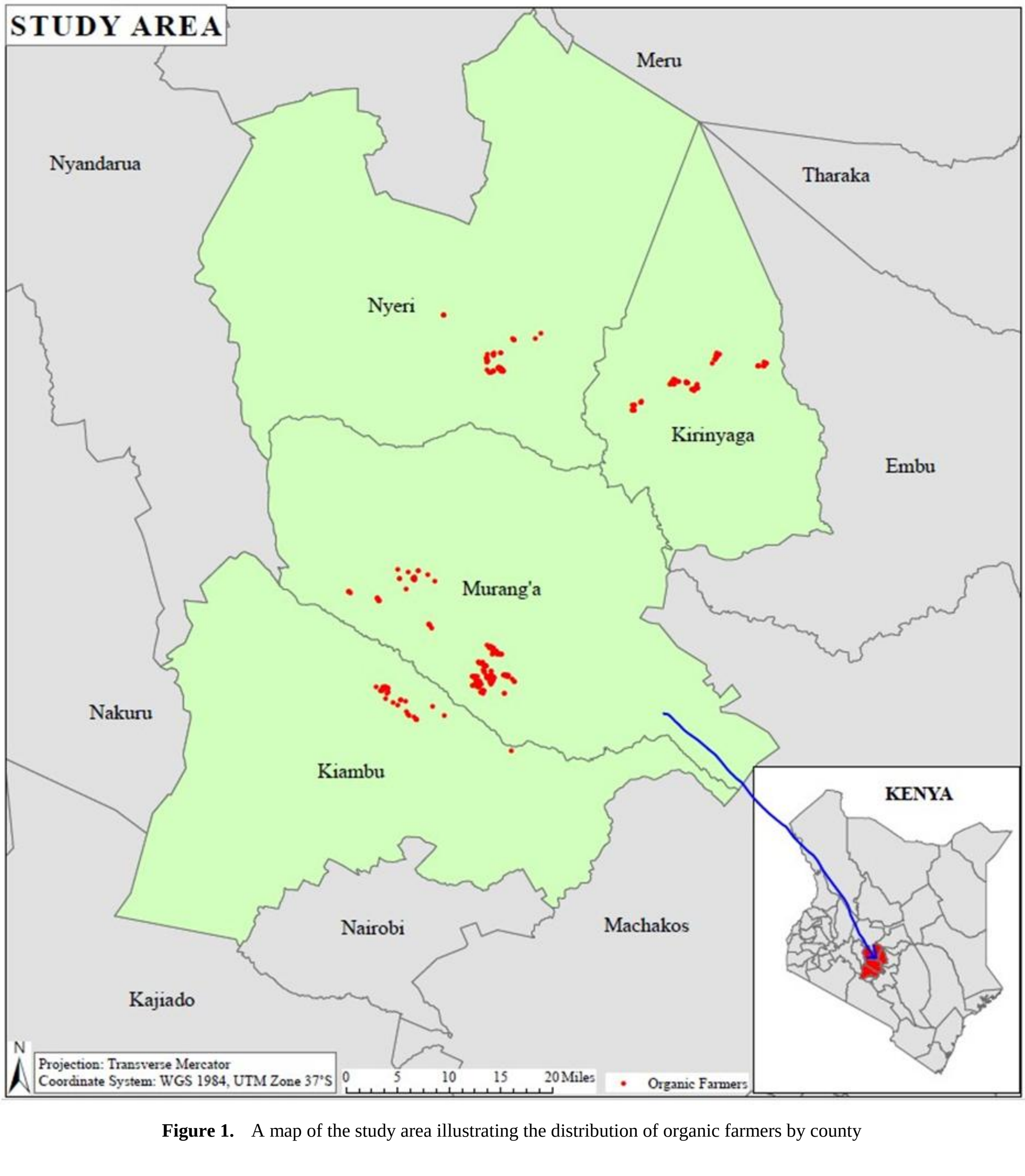

Figure 1. A map of the study area illustrating the distribution of organic farmers by county

ANN analysis was conducted in ArcMap version 10.6.1 to determine if the distribution of organic farms were random, dispersed, or clustered. The ANN tool calculates the nearest neighbor index based on the average distance from each feature to its nearest neighboring feature (Fischer & Getis, 2010). If the average distance is less than the average for a hypothetical random distribution, the distribution of the features being analysed is considered clustered. If the average distance is greater than a hypothetical random distribution, the features are considered dispersed (ESRI, 2018). The index is expressed as the ratio of the observed distance divided by the expected distance. The null hypothesis was tested at 95% level of significance.

Spatial autocorrelation of organic farms was assessed using local Moran's index (*I*). The local Moran's *I* is computed as follows;

$$I_i = z_i \sum_j w_{ij} z_j \tag{5}$$

Where z_i and z_j are standardized scores of attribute values for unit *i* and *j*, and *j* is among the identified neighbors of *i* according to the weights matrix w_{ij} (Anselin, Kho, & Syabri, 2004). Moran's *I* require a weights matrix that defines a local neighborhood around each geographic unit. Therefore, before bivariate Moran's *I* was conducted, a weight matrix was created using queen contiguity. The value at each unit is compared with the weighted average of the values of its neighbors. A weights file identifies the neighbors and it is calculated from the distance between points. The formulae of each weight are as follows;

$w_{ij} = \frac{C_{ij}}{\sum_{j=1}^{N} C_{ij}}$ with $C_{ij}=1$ when *i* is linked to *j*, and $C_{ij}=0$ when otherwise (Anselin, Kho, & Syabri, 2004).

4. Results and Discussion

Organic Crop Production in Central Kenya

Most of the organic farmers (*n* = 233, 71.3%) owned between one and four acres as presented in Table 1. The average acreage under OA was *M* = 2.09, *SD* = 1.71, although the farm sizes ranged from .025 to 13 acres. The results in Table 1 indicate that many of the farmers (*n* = 125, 38.3%) earned less than Kshs 100,000 annually. The annual incomes from organic crops ranged from Kshs 2,500 ($25) to Kshs 3,200,000 ($32,000) (*M* = 267,352.01, *SD* = 462,577.39). Among Central Kenya counties, Murang'a dominated both in avocado and macadamia production, thus its farmers reported much higher income levels than the other counties. The production of avocado and macadamia has in recent years overtaken coffee and tea growing, both of which have been the main cash crops in the region for centuries (Bagal, Belleti, Marescotti & Onori, 2013). Other than avocado and macadamia crops, organic farmers in the region participated in the production of tea, coffee, pineapples, maize, beans, bananas, and fresh vegetables.

Table 1. Distribution of Respondents by Farm Sizes[a] and Income Levels[b] (N= 327)

Acreage	Frequency (n)	Percent
Less than 1	65	19.9
1- 4	233	71.3
5 - 8	28	8.6
Over 8	1	.3
Income levels		
Less than 100,000	125	38.3
100,001 – 250,000	109	33.4
250,001 – 500,000	53	16.3
500,001 – 750,000	22	6.7
750,001 – 1,000,000	4	1.2
Above 1,000,000	13	4.0

Note. [a]*M* = 2.09, *SD* = 1.71; [b]*M* = 267,352, *SD* = 462,577.39

Spatial Trends of Organic Crop Production

The first objective sought to analyze the spatial trends of organic crop production in Central Kenya. As reported in Figure 2, the mean annual acreage ranged from between .81 to 1.55 acres in the four counties. Murang'a emerged as the topmost county with regards to acreage under OA. The mean acreage increased from .98 acres in 2012 to 1.72 acres in 2017 in Murang'a County. The mean annual acreage under OA was Kirinyaga with an acreage of .55 acres in 2012 and 1.19 acres in 2017.

A Mann Kendall trend test was performed to analyze trends in acreage under OA. As indicated in Table 2, there were significant upward trends in acreage under OA between 2012 and 2017. The mean acreage under OA in the four counties rose significantly from *M* = 264.88, τ = .0.44, *p* < .05 to *M* = 508.95, τ = .95, p < .05 in 2017. This shows that the acreage under OA almost doubled. The upward trends can be attributed to increasing global demand for organic produce and the rising food safety concerns (Gikunda & Lawver, 2019). As noted by Carvalho, (2017), the contamination of the ecosystems through application of agrochemical and the subsequent compromise of food safety among other factors are the driving forces toward changes in farming systems.

Table 2. Mann Kendall Statistics for Trends of OA Acreage between 2012-2017

Year	Acreage	*Tau* (τ)	σ^2	*p*	Trends 95% significance
2017	508.95	0.95	3569631	< .05	Upward
2016	498.53	0.85	3564745	< .05	Upward
2015	415.25	0.72	3527234	< .05	Upward
2014	349.05	0.6	3486337	< .05	Upward
2013	309.68	0.51	3331465	< .05	Upward
2012	264.88	0.44	3057771	< .05	Upward

p <.05

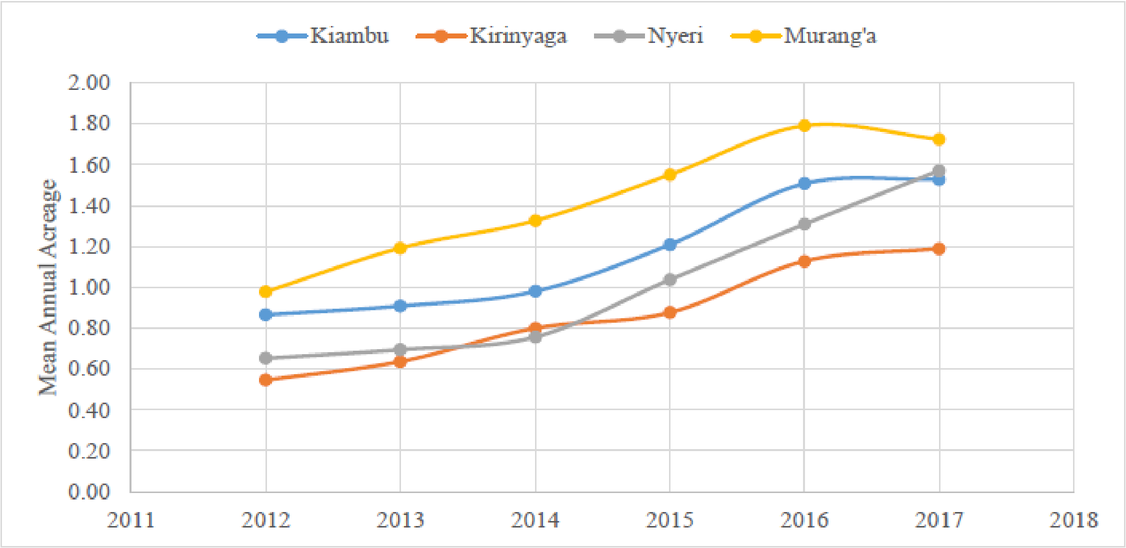

Figure 2. Mean annual acreage under organic crop production (N = 329)

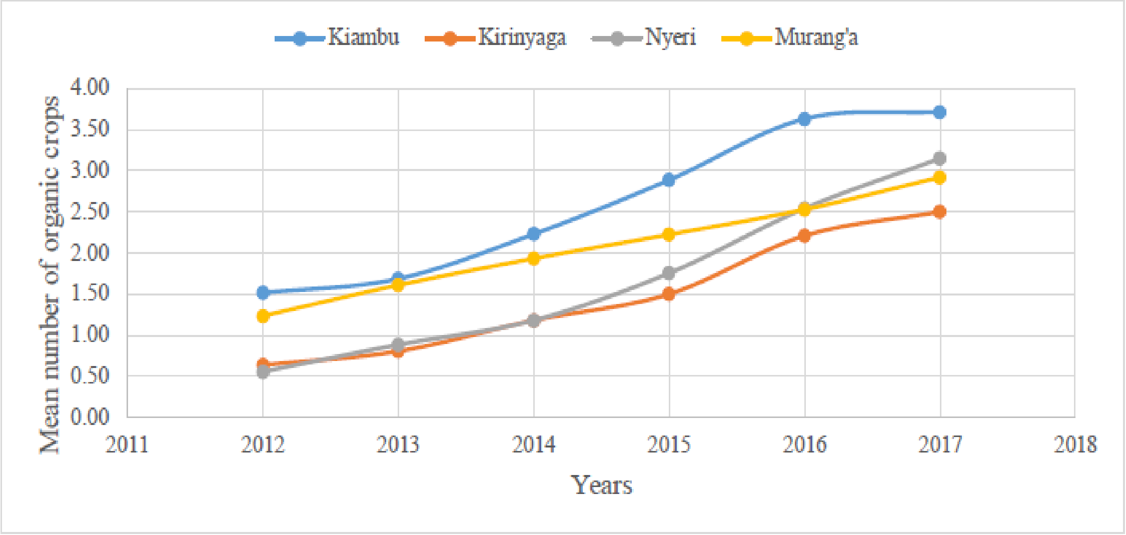

Figure 3. Mean number of organic crops per farmer by county (N = 329)

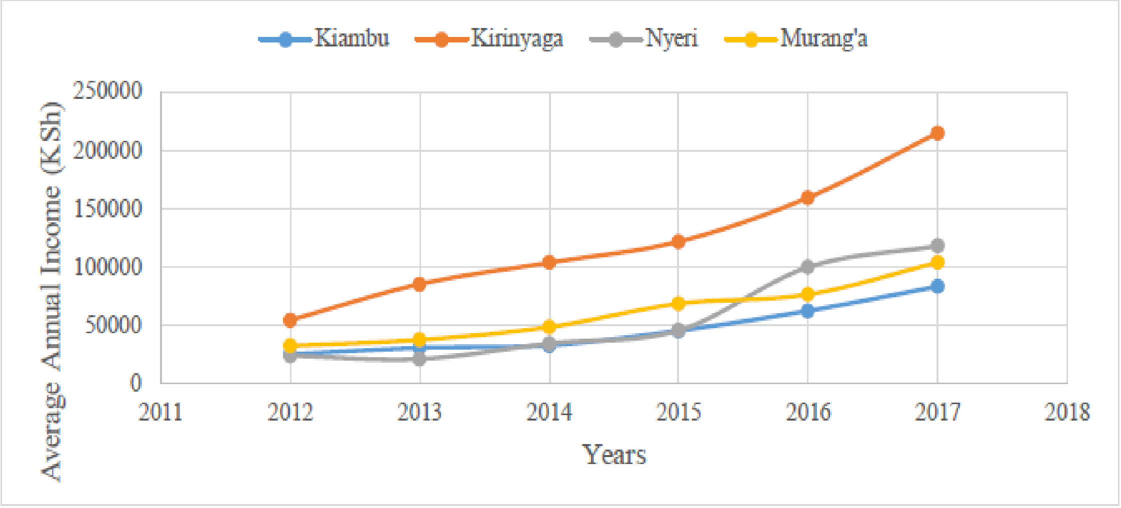

Figure 4. Mean annual organic crops' income by county (N = 329)

The results showed (Figure 3) that farmers in Kiambu County grew more organic crops compared to other counties between 2012 (*M* = 1.51) and 2017 (*M* = 3.71). The number of crops per farmer in a year ranged from 1 to 4 crops. Nearly all the farmers practice mixed farming so as to spread out the risks that come with crop failure and fluctuating produce prices. Kirinyaga County reported the least number of crops within the period. However, there was a general increase in the number of crops across the counties.

As shown in Figure 4, there was a general increase in annual income generated through the sale of organic produce. The mean annual organic crop income ranged from KShs 25,406 (*M* = $ 254.06) in 2012 to KShs 104,040 (*M* = $ 1040.40). Organic farmers from Kirinyaga County reported higher annual income than the rest of the counties while Kiambu County was least. The higher levels organic produce sales and income levels in Kirinyaga County can be attributed to proximity to market (the county is close to the highway) and production of organic avocado and vegetables which attracts higher prices.

Spatial Distribution of Organic Farm

Objective two sought to describe the spatial distribution of organic crop production in Central Kenya. The main organic crops produced in the region were avocado and macadamia. Table 3 presents the percentage and frequencies of organic farms producing avocado and/or macadamia in Kiambu, Kirinyaga, Murang’a, and Nyeri counties. Overall, the majority of the organic farmers (*n* = 144, 43.77%) producing avocado and macadamia (*n* = 69, 20%) were found in Murang'a County. The findings suggest OA was higher in Murang'a and least in Kiambu County. The concentration of OA in Murang'a County may have been brought about by the availability of markets, information access, social networks, favorable climate, and soils suitable for the production of organic macadamia and avocado among other crops (Läpple & Cullinan, 2012).

Table 3. Distribution of Farms Producing Avocado and Macadamia (N = 329)

Main organic crops		Counties							
		Kiambu		Kirinyaga		Murang'a		Nyeri	
	Participation	*n*	%	*n*	%	*N*	%	*n*	%
Avocado	No	2	5.71	42	58.33	18	11.11	17	28.33
	Yes	33	94.29	30	41.67	144	88.89	43	71.67
Macadamia	No	14	40.00	21	29.17	93	57.41	33	55.00
	Yes	21	60.00	51	70.83	69	42.59	27	45.00

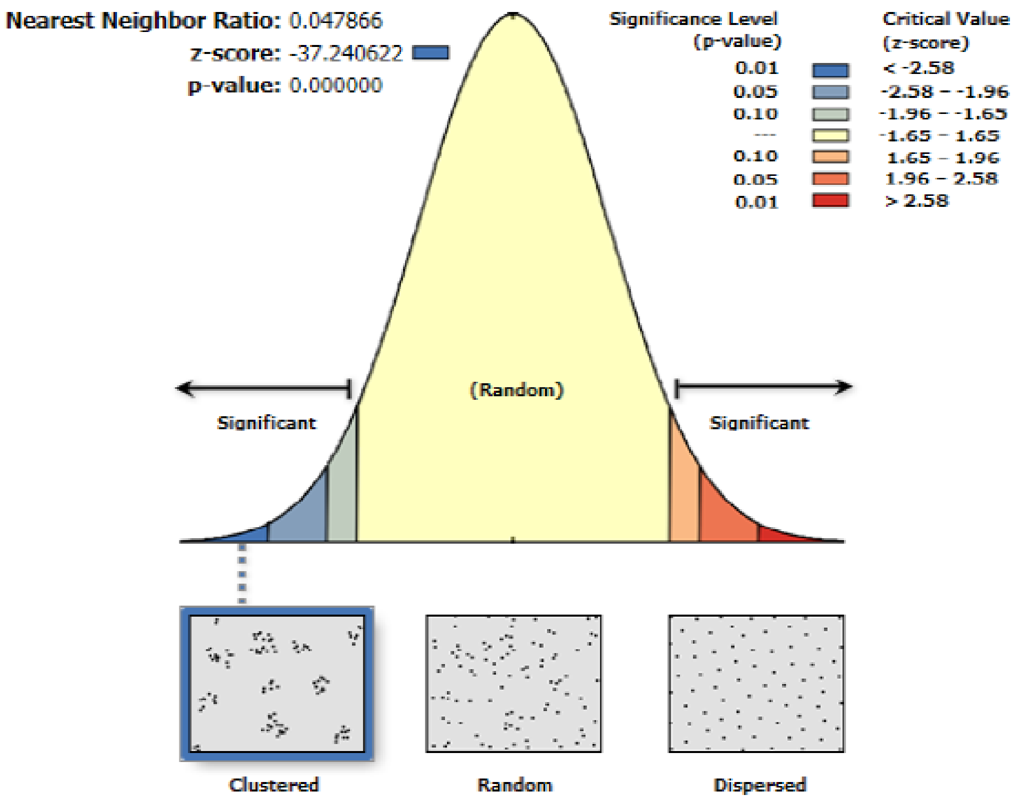

Figure 5. Spatial distribution patterns of organic macadamia and avocado farms (N = 329)

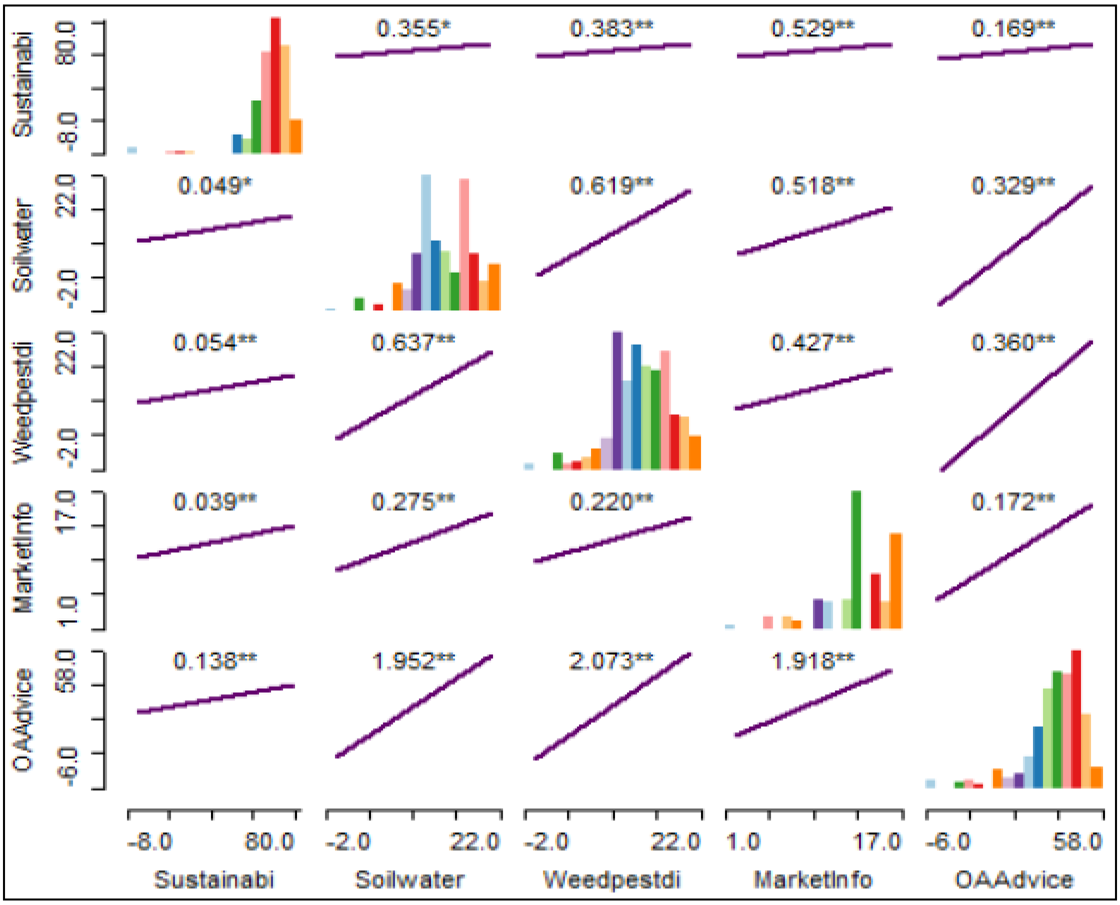

Figure 6. Spatial autocorrelation statistics for sustainability and organic agricultural advice on produce market, soil, water, weed, pest and disease management practices (*N* =329); Organic farms Moran's, *I* = .23, *p* = .001

ANN test was used to analyze the distribution to establish whether macadamia and avocado farms exhibited random, clustered, or dispersed patterns. Dacey (1960) observed that the nearest neighbor index value of 1.0 provides the standard randomness, increasing index values are indicative of increasing dispersion and decreasing index values provide evidence of increasing clustering. Taylor (1977) noted that the nearest neighbor statistic will produce values between 0 and 2.15 from which we infer whether the distribution pattern is clustered, random, or dispersed. ANN is used to test the null hypothesis, which states that features exhibit a random pattern. As reported in Figure 5, there was less than 1% likelihood that this clustered pattern could be the result of random chance, $p < .05$, $Z = -37.24$. Therefore, the null hypothesis was rejected, meaning that organic farms exhibited a statistically significant clustering. This is further supported by the nearest neighbor index of .05, which also signifies clustering patterns. In order to enhance the accuracy and reliability of position estimates, the receiver's Wide Area Augmentation System (WAAS) was enabled.

By identifying the clusters of various organic crops, policymakers are better able to formulate regional level policies (Holloway & Lapar, 2007) which, when adopted, could aid the growth of the crop enterprises in question. Naik and Nagadevara (2012) observed that spatial clusters have become very successful in boosting economic development in many countries as they facilitate strategic planning. A clear understanding of organic macadamia and avocado farm clusters is of paramount importance to extension educators for the planning and dissemination of agricultural technologies related to the production and management of the crops.

The clusters make it possible for extension educators to prepare, package, and disseminate appropriate macadamia and avocado crop practices and technologies suited for specific geographic locations. The choice of extension methods, whether individual, group, or mass, for use in the dissemination of the technologies would be made easier and more informed were they to be based on spatial cluster information linked with farmer characteristics. There was a positive spatial autocorrelation of organic farms (Moran's $I = .23$, $p = .001$). This shows that the farms were concentrated at certain parts of the region, thus confirming the results of ANN. As shown in Figure 6, there were positive spatial autocorrelations between OA advice ($I = .17$, $p < .01$), its elements, and sustainability. Among the elements of OA advice, market information ($I = .53$, $p < .01$) was highly autocorrelated with sustainability of OA. This shows that information about the marketing of organic produce was higher in areas where farmers were clustered than in areas where they were not.

The study also estimated the positional errors that were associated with organic farms' waypoints. The estimated positional errors (EPE) ranged from 2.74 m to 3.66 m with a mean of 2.76 m as shown in Table 4. Zandbergen and Arnold (2011) reported that GPS accuracy is influenced by factors such as satellite position, atmospheric conditions, noise in the radio signal, and natural barriers like buildings and trees. The accuracy of the waypoints may have been affected by atmospheric conditions. Typical GPS accuracy has been reported to be within 10m of actual position for consumer-grade receivers (Wing, 2011). Therefore, the deviations witnessed in the study's waypoints were small.

Table 4. Estimated Positional Errors Associated with Farms Waypoints (N = 328)

EPE (meters)	Frequency	Percent
2.74	314	95.7
3.05	12	3.7
3.66	2	.6
Total	328	100.0

Mean Estimated Positional Error = 2.76 m, *SD* =.30

5. Conclusions and Implications

Most of the organic farmers in Central Kenya are small-scale as their agricultural activities take place on between one and four acres. However, there was an upward trend in organic crop production between 2012 and 2017. More conventional agricultural farmers converted to OA, thus acreage and income emanating from organic crop production increased. Farmers gradually moved from the production of one variety of crop to several varieties. The mean acreage per farmer rose by 48% from .81 acres in 2012 to 1.55 acres in 2017. Murang'a emerged as the topmost county with regards to acreage under OA. The annual income from organic crops increased by 84% from KShs 29,926 ($299.26) in 2012 to KShs 181,635 ($1816.35) in 2017. Kirinyaga County reported the highest average annual income while Kiambu County grew the highest number of organic crops. Many of the farmers participated in the production of organic macadamia and avocado. Other organic crops are grown in the region including tea, coffee, pineapples, maize, beans, bananas, and vegetables.

A majority of the organic farms especially those producing macadamia and avocado in Central Kenya were clustered. A high concentration of both avocado and macadamia production was witnessed in Murang'a County as compared to other counties in Central Kenya. Among the four counties comprising the study area, Nyeri had the least number of organic farms engaged in the production of the two crops. The clustering allowed the organic farmers to share resources such as production and marketing information, and collectively market their produce (Gikunda & Lawver, 2019). The clustering of the organic farms may have been brought about by a number of factors. Many of the organic farmers, especially those certified, are organized in groups and members of these groups owned farms that were closely located. It is apparent that farmers located in the same area and producing similar crops would want to benefit from positive outcomes associated with group marketing, access to finance, and economies of scale (Gikunda & Lawver, 2018).

Macadamia and avocado have become lucrative produce with the establishment of packing houses and holding facilities in the region to process and export fresh produce. A kilo of certified macadamia sell for between 180 and 250 KShs while the certified avocado farm gate price is between 8 and 16 KShs, depending on the quality. Most of the organic farms were found concentrated around the organic packing houses and holding facilities established by local and external companies such as Kakuzi, Jungle Nut, Sasini, etc. These companies had contracted farmers around their vicinity to grow organic produce for them. Each of the companies has employed its own extension agents to disseminate OA information to its contracted farmers. The concentration of the farmers around the packing houses and holding facilities and skewed dissemination of OA practices also contributed to the clustered patterns (Greene & Kremen, 2003) witnessed.

Environmental factors, including ecological conditions and soils favorable for the production of certain crops, like macadamia and avocado, in certain locations of the study area also accounted for the clustered application of the OA practices as revealed by the findings. The altitude of the sampled farms ranged between 1650 and 2100 m above sea level, temperatures of between 52 and 79 degrees Fahrenheit (11 to 26 degrees Celsius) (FAO, 2012) favored the production of the two major organic crops. The clustering of organic farms is not only beneficial to farmers but also to the companies, extension services, and policymakers. The concentration of farms around the companies eases the transport of raw nuts and avocado and thus reduces the transport costs. With the knowledge of where farmers are concentrated, extension educators are better able to plan, package, and disseminate localized and crop-based OA information to the farmers. Knowledge of clusters eases communication as it serves as one of the criteria that guide the choice of communication mode.

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REFERENCES

[1] Ahlem, Z., & Hammas, M. (2017). Organic farming: A path of sustainable development. *International Journal of Economics & Management Sciences, 6*(5), 465. doi:10.4172/2162-6359.1000456.

[2] Anselin, L., Kho, Y., & Syabri, I. (2004). Web-based analytical tools for the exploration of spatial data. *Journal of Geographical Systems, 6*, 197–218.

[3] Bagal, M., Belleti, G., Marescotti, A., & Onori, G. (2013). *Study on the potential of marketing of Kenyan Coffee as Geographical Indication.* Lausanne switzerland: European Commission.

[4] Bagi, F., & Reeder, R. (2012). Factors affecting farmer participation in agritourism. *Agricultural and Resource Economics Review, 41*(2), 189-199. doi:10.1017/S1068280500003348.

[5] Bichler, B., Häring, A., Dabbert, S., & Lippert, C. (2005). *Determinants of Spatial Distribution of Organic Farming in Germany.* Adelaide, Australia: Researching Sustainable Systems.

[6] Carvalho, F. P. (2017). Pesticides, environment, and food safety. *Food and Energy Security, 6*(2), 48-60. doi:10.1002/fes3.108|.

[7] Dacey, M. F. (1960). The spacing of river towns. *Annals of the Association of American Geographers, 50*, 59-61. doi:10.1111/j.1467-8306.1960.tb00332.x|.

[8] Eades, D., & Brown, C. (2006). *Identifying Spatial Clusters within U.S. Organic Agriculture.* Morgantown,: Regional Research Institute, West Virginia University.

[9] ESRI. (2018, 7 2). *ESRI Developer Network*. Retrieved from How Average Nearest Neighbor Distance (Spatial Statistics) works: http://edndoc.esri.com/arcobjects/9.2/java/shared/geoprocessing/spatial_statistics_tools/how_average_nearest_neighbor_distance_spatial_statistics_works.htm.

[10] FAO. (2012). *Organic agriculture and the law.* Rome, Italy: Food and Agricultural Organization.

[11] Fischer, M., & Getis, A. (2010). *Handbook of Applied Spatial Analysis: Software Tools, Methods and Applications.* New York: Springer.

[12] Franzel, S., Wambugu, C., & Tuwei, P. (2003). Adoption and dissemination of fodder shrubs in Central Kenya. *Agricultural Research and Extension Network*, 1-11.

[13] Gabriel, D., Carver, S., Durham, H., Kunin, W., Palmer, R., Sait, S., . . . Benton, T. (2009). The spatial aggregation of organic farming in England and its underlying environmental correlates. *Journal of Applied Ecology, 46*, 323–333. doi:10.1111/j.1365- 2664.2009.01624.x.

[14] Gikunda, R. M., & Griffith, C. (2019). Appropriateness of handheld Garmin GpsMap 76csx in urban tree inventory. *American Journal of Geographic Information System, 8*(3), 119- 125. doi:10.5923/j.ajgis.20190803.01.

[15] Gikunda, R. M., & Lawver, D. E. (2018). Influence of Smallholder Farmer Groups on the Application of Best Horticultural Farming Practices in Kenya. *34th Annual Conference of AIAEE Celebrating the Intersection of Human, Natural, and Cultural Systems, April 16 - 20, 2018* (pp. 52-53). Merida, Mexico: Association for International Agricultural and Extension Education.

[16] Gikunda, R. M., & Lawver, D. E. (2019). Group cohesion and application of best horticultural farming practices among farmer groups in Meru County, Kenya. *Journal of International Agricultural and Extension Education, 26*(1), 60-72. doi:doi: 10.5191/jiaee.2019.26106.

[17] Greene, C., & Kremen, A. (2003). *U.S. Organic Farming in 2000-2001: Adoption of Certified Systems.* U.S. Department of Agriculture, Economic Research Service.

[18] Holloway, G., & Lapar, M. (2007). How Big is Your Neighbourhood? Spatial Implications of Market Participation Among Filipino Smallholders. *Journal of Agricultural Economics, 58*(1), 37-60. doi:doi.org/10.1111/j.1477-9552.2007.00077.x.

[19] Kacprzak, E., & Mackiewicz, B. (2014). The distribution systems for organic farming produce in Poland and Spain similarities and differences. *Journal of the Geographical Society of Berlin, 145*(3), 175-190. doi:10.12854/erde-145-16.

[20] Kendall, M. G. (1975). *Rank Correlation Methods* (4th ed.). Charles Griffith.

[21] Kenya National Bureau of Statistics. (2010). *The 2009 Kenya population and housing census.* Nairobi: Kenya National Bureau of Statistics (KNBS).

[22] Läpple, D., & Cullinan, J. (2012). The development and geographic distribution of organic farming in Ireland. *Irish Geography, 45*(1), 67-85. doi:10.1080/00750778.2012.698585.

[23] Läpple, D., & Kelley, H. (2015). Spatial dependence in the adoption of organic drystock farming in Ireland. *European Review of Agricultural Economics, 42*(2), 315–337. doi:10.1093/erae/jbu024.

[24] Lewis, D., Barham, B., & Robinson, R. (2011). Land in the adoption of clean technology? The case of organic dairy farming. *Land Economics, 87*(2), 250-267.

[25] Limpisathian, P. (2011). *Geographic Information System in Agriculture and Precision Farming.* Pennsylvania: Pennsylvania State University.

[26] Mani, V., Agarwal, R., Gunasekaran, A., Papadopoulos, T., Dubey, R., & Childe, S. (2016). Social sustainability in the supply chain: Construct development and measurement validation. *Ecological Indicators Journal, 71*, 270–279.

[27] Mattar, C., Sobrino, J. A., Julien, Y., & Morales, L. (2011). Trends in column integrated water vapour over Europe from 1973 to 2003. *International Journal of Climatology, 31*, 1749–1757 . doi:10.1002/joc.2186.

[28] Morone, P., Sisto, R., & Taylor, R. (2006). Knowledge diffusion and networking in the organic production sector: a case study. *Eurochoices, 5*(3), 40-46. doi:10.1515/opag-2019-0012.

[29] Naik, G., & Nagadevara, V. (2012). *Spatial Clusters in Organic Farming – A Case Study of Pulses Cultivation in Karnataka.* Bangalore: Indian Institute of Management.

[30] Ning, T., Wickert, J., Deng, Z., Heise, S., Dick, G., Vey, S., & Schöne, T. (2016). Homogenized Time series of the

atmospheric water vapor content obtained from the GNSS reprocessed data. *Journal of Climate, 29*, 2443-2456. doi:10.1175/JCLI-D-15-0158.1.

[31] Parker, D. C., & Munroe, D. K. (2007). The geography of market failure: edge-effect externalities and the location and production patterns of organic farming. *Ecological Economics, 60*(4), 821–833. doi:10.1016/j.ecolecon.2006.02.002.

[32] Parker, D., & Munroe, D. (2004). Spatial tests for edge-effect externalities and external scale economies in California certified organic agriculture. *American Agricultural Economics Association Annual Meeting.* Denver: CO.

[33] Platnick, S., King, M., Ackerman, S., Menzel, W., Baum, B., Riédi, J., & Frey, R. (2003). The MODIS cloud products: Algorithms and examples from Terra. *IEEE Transaction Geoscience and Remote Sensing*, 459-473.

[34] Schmidtner, E., Lippert, C., Engler, B., Haring, A., Aurbacher, J., & Dabbert, S. (2012). Spatial distribution of organic farming in Germany: does neighbourhood matter. *European Review of Agricultural Economics, 39*(4), 661–683.

[35] Taylor, P. J. (1977). *Quantitative methods in geography*. Boston: Houghton Mifflin.

[36] Vos, T. (2000). Visions of the middle landscape: Organic farming and the politics of nature. *Agriculture and Human Values*, 245-256.

[37] Wing, M. (2011). Consumer-Grade GPS Receiver Measurement Accuracy in Varying Forest Conditions. *Research Journal of Forestry, 5*(2), 78-88. doi:10.3923/rjf.2011.78.88.

[38] Wollni, M., & Andersson, C. (2014). Spatial patterns of organic agriculture adoption: Evidence from Honduras. *Ecological Economics*, 120-128. doi:10.1016/j.ecolecon.2013.11.010.

[39] Zandbergen, P., & Arnold, L. (2011). Positional accuracy of the wide area augmentation system in consumer-grade GPS units. *Computers and Geosciences, 37*(7), 883-892. doi:10.1016/j.cageo.2010.12.011.