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An investigation of microclimatic influence of a forest edge micro-climate on agricultural production

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Abstract

Human social structures and their development significantly depend on the maintenance and conservation of the environmental resources they require for survival. Forests have been known to be sources of raw materials and resources for sectors of human livelihoods such as healthcare, household uses and agriculture, among others. Understanding the influence of forests on agriculture not only improves the agricultural practices but also enhances eco-friendly development and sustainability. This paper investigates the relationship between forest edge microclimates and agricultural cropproduction. The study adopted a Bio-geographical approach buttressed on the Mono-Climax Theory (MCT) and Holdridge's Deterministic Approach (HAD). Data for this study comprised of agricultural cropproduction for 2012 collected from farmers along the edge of Thathe Forest in Limpopo, South Africa,in all the four cardinal directions. Vegetation density and composition from the forest edge in all the four cardinal directions was collected through quadrats. Linear regression between agricultural productivity, as the dependent variable, and vegetation composition and density, as independent variables, was employed to determine the relationship. Results reveal that agricultural crop production, vegetation density decrease andcomposition change as one moves from the forest edge. We conclude that Thathe forest creates an important micro-climate for agriculture. As such the forest should be conserved for sustainable agricultural production and development.

Key terms: Micro-climate,Bio-geographical, sustainability, vegetation, agriculture.

1. Background

Climate is the atmospheric conditions of a place over a long period of time. The concept of climate is further divided into four sub-categories based on their spatial and temporal attributes. These categories are micro, macro, synoptic and meso-scales. The micro-scale is the one most relevant to this study. The size of a micro-climate depends on the size of the creating features (Hauk et al., 2012) which include topography, soil type and vegetation (Kurtural et al., 2007).

In a forest environment the micro-climate is further divided into two sub-categories which are understory and edge micro-climate (Chen, 1999). Understory micro-climate is created by the shadowing effect of the forest canopy on the region below (Hauk et al., 2012). The edge micro-climate is a climatic gradient across the forest edge extending from the edge towards the centre and also from the edge outwards (Norris, 2012). The understory micro-climate is influenced by a number of factors with radiation as the

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major one. Only 1% of the incoming radiation reaches the forest floor and therefore limits undergrowth (Norris, 2012). This is why the forest floor is not heavily vegetated in many tropical forests.

Climate and vegetation are joined in a deterministic relationship where they influence each other symbiotically such that one's influence is visible in the other (Brovkin, 2002). Micro-climates influence many in terms of fauna-flora ecological and physiological processes (Yu & Hien, 2006). The tropics are associated with tropical forests and the drier subtropics are associated with the tundra deserts. The central thesis in the study of plant ecology is that climate dominantly controls the spatial distribution of the major vegetation types (Brovkin, 2002). Vegetation cover in turn influences climate by altering the physical characteristics of the land such as roughness, albedo, bio-geographical cyclesand atmospheric gas composition (Hauk et al., 2012) as well as micro-scale atmospheric circulation.

The forest edge micro-climateis significantly influenced by the characteristics of transition zone. The transition zoneis the area where the domain of the forest ends and the surrounding area begins. Wright (2010) and Kurtural et al., (2007) point out that forest edge micro-climates that transition into a zone occupied by agricultural practices have different characteristics from the ones that transition into natural vegetation. Spangeberg et al (2008) used simulation models in comparison with actual on-site data and came to the conclusion that vegetation in the form of trees has a significant influence on the micro-climate variations as compared to ground based vegetation like grass and shrubs.

Smith et al (2008) observed that in an ideal setting, any vegetation should have its own distinct micro-climate. As such a forest environment tends to experience a climate that is different from that of the surrounding areas. This micro-climate should ideally be localized to the creating factor. The atmosphere above a heavily vegetated forest is influenced by the structure and type of vegetation below (Mühlenberg *et al*., 2012; Von Arx *et al*., 2012). The micro-climate variables of a forest change from edge to interior where the air temperature becomes constant (Medellu *et al*., 2012). However, the pattern is different from edge outwards.

The study was conducted in the Thathe region located in South Africa on the northern slopes of the Venda area in the eastern side of the Soutpansberg region of the Limpopo province. The forest area is located at 22.88S and 30.13E. At an altitude of 1224.22m above sea level, montane vegetation forms Thathe Forest. The area is in the north-eastern part of South Africa which has a subtropical climate with cold winters from June through August and hot summers from November through March.

The aim of this study was to assess the extent to which Thathe forest influences the ambient micro-climate and the impact on agricultural crop production. Following this background is the methodology and results. The paper closes with some concluding remarks.

2. Methodology
2.1. Theoretical Background

The study of micro-climates has evolved through a range of methods of analysis. These methods were based on different theories developed over time. These include Koppen's Classification System (KCS)(1884), Holdridge Life Zone Classification (HLZC) (1947), BIOME and KCCS (Brovkin, 1997) among others. This study was guided by two theories -the Mono-Climax Theory (MCT) developed by Clemens (1936) and Holdridge's Deterministic Symbiosis Approach (HDSA) developed by Holdridge in 1947.

MCT states that the degree of deviation of vegetation from a theoretical climax can be determined and the factors responsible can be measured provided there is a yardstick for comparison (Brovkin *et al.*, 1999). This theory requires that for measurements to be made there must be a vegetation climax from which the measurements are said to deviate. The most important assumption is that climatic factors determine the dominant species found in a region and the distributional patterns thereof (Meeker and Merkel, 1984). It is this theory that was used to relate the forest micro-climate to the surrounding natural vegetation and agricultural practices.

In MCT applications, the climax vegetation could be temporal or spatial. The temporal application is when vegetation is measured and compared to a previous time when it was at its climax stage. In the spatial application, vegetation is measured in comparison to another area that occupies a different geographical location that is at a climax stage. The spatial attribute of the MCT was adopted for this research. Thathe forest was the climax vegetation because it has been maintained in its natural. As such, the forest was the initial point of reference.

The second theory is Holdridge's Deterministic Symbiosis Approach (HDSA). HDSA posits that the changes in the micro-climate cause response changes in the vegetation and vice versa (Brovkin *et al.*, 1997). HDSA considers the relationship between vegetation and micro-climate to be at an equilibrium level of symbiosis where they equally influence each other. This was fundamental to this study where the extension of the micro-climate was measured through changes in vegetation. The HDSA attributes any deviation of the surrounding vegetation from the forest climax vegetation to changes in the ambient micro-climate.

These two theories have two sub approaches to micro-climate studies. The Meteorological Approach (MA) and the Bio-geographical approach (BGA). We adopted the BGA. The BGA uses bio-geographical elements such as vegetation and fauna in the assessment of micro-climates (Godefroid, 2012; Hauk et al., 2012).

2.2. Data collection

Vegetation and agriculture production data were collected using quadrats and interviews, respectively. Quadrats were chosen because they are smaller and are usable areas in natural vegetation. We established quadrats, each covering 25km² at 500m intervals along 3km stretches in all cardinal directions. This resulted in seven quadrats in each side of the forest.

Ideally, the first quadrat, also called the zero point, should be at the edge of the forest. However, the western side of the forest transitions into a pine tree plantation, obscuring the forest edge. Consequently, taking the forest edge on the west as the zero point would have meant that the zero point quadrats would be composed of plantation vegetation.We therefore place zero point quadrats on the western side at 100m to avoid the bias caused by the plantation.

The southern side of Thathe forest has the Thathe Vondo Dam and a tea plantation, which made it difficult to establish quadrats. We, therefore set one quadrat immediately after the dam before the tea plantation starts just about1km from the dam. After the tea plantation there is a mountain which meant that quadrats could only be established at 2.5km and 3km, culminating in three quadrats instead of the seven on the other sides.

The vegetation characteristics measured within the quadrats are the vegetation density, the total number of tall non-shrub trees within the plotsand the number of units within the quadrat (shrubs and non-shrubs).The focus on non-shrub trees is based on the definition of a forest by Kjellsen(2006) and a study conducted by Hauk et al (2012) where the primary influence of a forest on the ambient micro-climate is seen through the distribution of non-shrub trees.

Purposive sampling was adopted to select farms from which to collect agricultural crop production data. Thathe forest is surrounded by 18villages which practice crop production. We considered the presence of mountains between the forest and the villages as an influential factor on micro-climates. This consequently influenced the selection of villages from which to collect crop production data. Eight villages had no mountain hence qualified as sources for agriculture production data.

In this region maize is cultivated in the summer and has a growth period of 120-140 days (Du Plessis, 2003). Once harvested, the unit of measurement for the grain is an 80kg bag (Gouse, 2012). This was adopted for the study for measuring grain produced by each farmer. The grain production data was then collected through structured questionnaire.

2.3 Data Analysis and Presentation

2.3.1 Vegetation changes and distance from forest edge relationship

Quadrat proportion and vegetation density are the two important variables which indicate micro-climate changes. The quadrat proportion, calculated using Equation 1, is a mathematical representation of the fraction of the quadrat that is occupied by non-shrub trees. According to BGA relative to this study, the changes in the quadrat proportion indicate the changes in the intensity of the micro-climate. The vegetation density is a cumulative average of the number of units that exist within a quarantined area. The use of vegetation density in microclimates is in calculating the quadrat proportion.

$$Quadrat\ Proportion\left(\frac{units^2}{m^2}\right) = Vegetation\ density \times Number\ of\ non-shrub\ trees \quad \textbf{Equation1}$$

$$Vegetation\ Density(units/m^2) = \left\{\frac{QUADRAT - Total\ Number\ of\ Units}{QUADRAT area}\right\} \quad \textbf{Equation 2}$$

Linear regression from Microsoft Excel was employed to determine the relationship between quadrat proportion and distance, with distance as the independent variable. The regression givesthedirection, significance and strength of a relationship between the input variables as represented by*r-value, r^2-value, Significance f, Slope coefficient, p-value, and standard error.*

2.3.2. Agricultural production and distance from forest edge relationship

Agricultural production data was collected for the assessment of the relationship between agricultural productivity and distance from the forest edge. Equation 3 was used to calculate agriculture productivity with respect to farm size. Agriculture production was the regressed against distance from the forest edge.

$$Agriculture\ Production\ (Kg/m^2) = \frac{GRAIN\ produced\ (in\ Kg)}{FARM\ size\ (in\ m^2)}$$

Equation 3

2.3.3. Micro-climate and agricultural productionrelationship

Agricultural production was regressed micro-climate intensity represented by quadrat proportion and distance from the forest edge. These analyses them produced the following results.

3. Results

3.1. Micro-climate intensity and distance from forest edge relationship

Table 1.1 and 1.2 below show the field as well as calculated data from the study.

Table1.1: Field and Calculated Vegetation data

Quadrat No:	**E1*	*E2*	*E3*	*E4*	*E5*	*E6*	*E7*	**W1*	*W2*	*W3*	*W4*	*W5*	*W6*	*W7*
Area (m^2):	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*
Units inside	*17*	*15*	*15*	*12*	*9*	*7*	*5*	*14*	*14*	*9*	*9*	*9*	*5*	*2*
Tall trees	*12*	*10*	*7*	*6*	*2*	*0*	*0*	*12*	*10*	*6*	*7*	*6*	*0*	*1*
Distance (m)	*100*	*500*	*1000*	*1500*	*2000*	*2500*	*3000*	*100*	*500*	*1000*	*1500*	*2000*	*2500*	*3000*
Vegetation density (units/m^2)	*0.68*	*0.6*	*0.6*	*0.48*	*0.36*	*0.28*	*0.2*	*0.56*	*0.56*	*0.36*	*0.36*	*0.36*	*0.2*	*0.08*
Quadrat Proportion (units²/m^2)	*8.16*	*6*	*4.2*	*2.88*	*0.72*	*0*	*0*	*6.72*	*5.6*	*2.16*	*2.52*	*2.16*	*0*	*0.08*

Table1.2: Field and calculated Vegetation data

Quadrat No:	**N1*	*N2*	*N3*	*N4*	*N5*	*N6*	*N7*	**S1*	*S2*	*S3*
Area (m^2)	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*	*25*
Units inside	*16*	*13*	*16*	*12*	*8*	*9*	*12*	*13*	*7*	*12*
Tall trees	*12*	*11*	*9*	*10*	*5*	*5*	*5*	*13*	*7*	*12*
Distance from forest edge (m)	*100*	*500*	*1000*	*1500*	*2000*	*2500*	*3000*	*1000*	*2500*	*3000*
Vegetation density (units/m^2)	*0.64*	*0.52*	*0.64*	*0.48*	*0.32*	*0.36*	*0.48*	*0.52*	*0.28*	*0.48*
Quadrat Proportion (units^2/m^2)	*7.68*	*5.72*	*5.76*	*4.8*	*1.6*	*1.8*	*2.4*	*6.76*	*1.96*	*5.76*

**W = Arbitrary representation of a quadrat on the Western side of the forest; *E = Arbitrary representation of a quadrat on the Eastern side of the forest; *S = Arbitrary representation of a quadrat on the Southern side of the forest; *N = Arbitrary representation of a quadrat to the Northern side of the forest.*

The regression of quadrat proportion against distance from the forest edge show that significant changes in vegetation as represented by quadrat proportion can be explained by distance from the forest edge (r^2 = 0.659). The relationship is strong (p-value = 0.026), significant (f = 0.026) in a negative direction (slope coefficient = 0.002).This means that the forest's influence on the micro-climate diminishes as the distance from the forest edge increases. Based on the regression and the graphical presentation we can deduce within a marginal error of 1.36 that the micro-climate intensity is stronger closer to the forest than it is away from it. This means that Thathe forest has an influence on the ambient micro-climate which gets weaker with increasing distance from the forest edge. This gradual decrease in the intensity of the micro-climate extends to a distance of 2.5km after which the influence of the forest is negligible.

3.2. Agricultural production and distance from forest edge

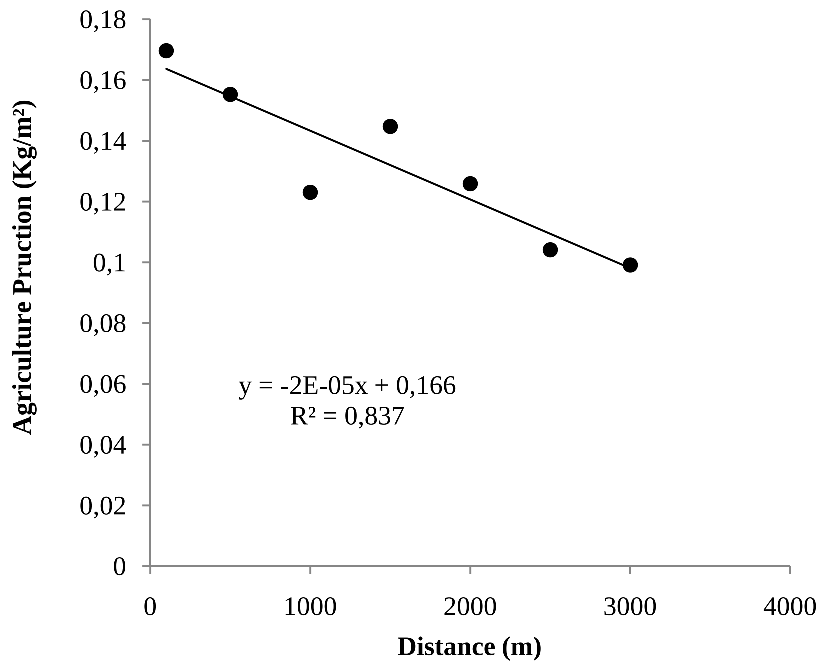
The data from questionnaires was analysed through regression between agricultural production and distance. Agriculture production was the dependent variable and distance was the independent variable. Figure1 shows the results of the regression.

Table 2.1: Farm and Calculated Agriculture data

Farm Number	**FW1*	*FW2*	*FW3*	*FW4*	*FW5*	*FW6*	**FE1*	*FE2*	*FE3*	*FE4*	*FE5*	*FE6*
Distance from Edge(m)	*105*	*500*	*1200*	*1800*	*2300*	*3000*	*120*	*470*	*1320*	*1800*	*2600*	*3000*
Farm Size(m^2)	*12000*	*9720*	*4550*	*16800*	*1440*	*9800*	*6630*	*10324*	*5732*	*4255*	*980*	*3320*
Grain (kg)	*2080*	*1440*	*560*	*2240*	*160*	*1120*	*1120*	*1680*	*800*	*480*	*80*	*320*
Agric Prod (kg/m^2)	*0.1733*	*0.1481*	*0.1231*	*0.1333*	*0.1111*	*0.1143*	*0.1689*	*0.1627*	*0.1396*	*0.1128*	*0.0816*	*0.0964*

Table2.2: Farm and Calculated Agriculture data

Farm Number	**FS1*	*FS2*	*FS3*	*FS4*	**FN 1*	*FN2*	*FN3*	*FN4*	*FN5*
Distance from Forest Edge (m)	*1890*	*2300*	*2760*	*3000*	*230*	*570*	*1420*	*1940*	*2600*
Farm Size (m²)	*9840*	*6535*	*1132 4*	*8756*	*1103 4*	*1032 4*	*8003*	*5012*	*1002*
Grain Produced (kg)	*1120*	*680*	*1240*	*760*	*1840*	*1600*	*1200*	*720*	*120*
Agriculture Production (kg/m²)	*0.113 8*	*0.104 1*	*0.109 5*	*0.086 8*	*0.166 8*	*0.155*	*0.149 9*	*0.143 7*	*0.119 8*



Significance f = 0.00383; r-value = 0.915; p-value = 0.0038; Standard error = 0.011525; Slope coefficient

Figure 1: *Scatter-gram analysis of Agriculture production against distance from forest edge*

The results show that agriculture production in between the sampled points can be predicted using the equation y = -2E-05x + 0.166 with a small marginal (0.011525). The significance F of 0.00383 suggests a statistically significant relationship between distance from the forest edge and agriculture productivity. The results also show that a significant proportion ($r^2 = 0.837$) agricultural production changes are explained by variations in distance from the forest edge. The regression results indicate that as distance from the forest edge increases, agricultural productivity decreases. The strength of this relationship is given by the r-value which is 0.915.

From these variables we can deduce that there exists a strong negative relationship between agriculture production and distance from the forest edge. The r^2-value indicates that as much as there are other factors that may determine agriculture production, distancefrom the forest edge is the most important one since it accounts for more than 80% of the variations.Agriculture production is higher closer to the forest and gradually decreasesas distance from the forest edge increases.

3.3. Micro-climate and agricultural production

The results significantly show a relationship between agriculture production and micro-climate intensity (P=0.0616). Based on this correlation, approximately 77% (r^2=0.773) of the variations in agriculture production patterns can be significantly (significance f = 0.023) explained by variations in microclimate intensity within an acceptable marginal error (0.012). The results support a strong (r = 0.59) and positive (slope = 0.004) relationship. The extra unsampled points of agriculture production can be predicted and interpolated using the output equation of the regression analysis (Equation (Y) $= 0.0039x + 1.1381$).

This means that an increase in the forest's influence on the ambient micro-climate causes an increase in agricultural productivity. The regression in this section explains that the patterns shown by these two variables are not coincidental but there is a relationship that a change in one results in a similar change in the other.

4. Concluding remarks

Results from this study reveal vegetation decrease with distance from the forest edge. There is a decrease in the density of non-shrub trees as the distance from the forest edge increases. This change in vegetation is directly proportional to the change in the intensity of the micro-climate of the forest. This agrees with Hauk et al (2012) who observed that a forest environment has its own specific micro-climate that is formed as a result of the vegetation type and density. .

This researchalso showed that the forest's micro-climate is not localized to the forest but extends outwards. This study also reveals thatafter adistance approaches 3km from the forest edge, the vegetation patterns show a less distinct change. This means that the forest's influence has diminished to a point where other natural and anthropogenic influences have a stronger influence on the vegetation distribution patterns than the forest.

According to LLCV (2013) the potential vegetation at any given place is determined by abiotic factors like climatic and soil factors. Each plant is suited for a certain kind of temperature range, moisture, acidity and other climatic and soil factors. This then means that a forest like micro-climate will always cause forest like vegetation which is composed mainly of non-shrub trees. We observed that there are more non-shrub trees where the forest's influence on micro-climate is higher and less non-shrub trees where the forest's influence is lower. Therefore we conclude that the high density of tall-trees observed at distances closer to the forest are a result of the forest's influence on the micro-climate being higher there.

Agriculture production gradually decreases as distance from the forest edge increases. There is higher production closer to the forest than there is farther from it. Therefore we can conclude that agriculture production changes are a response to variations in micro-climate intensity.

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