November. 2016. Vol. 7, No.1 ISSN 2311 -2476
International Journal of Research In Agriculture and Food Sciences

http://www.ijsk.org/ijrafs.html

THE INFLUENCE OF DISPERSED TREES ON MICROCLIMATIC CONDITIONS AND PRODUCTIVITY OF MAIZE (ZEA MAYS L.) IN AN ALNUS ACUMINATA AND MARKHAMIA LUTEA-BASED AGROFORESTRY SYSTEM IN HUMID VOLCANIC HIGHLAND REGION OF NORTH-WESTERN RWANDA

RUKANGANTAMBARA HAMOUD[1], MUNYAWERA JEAN BOSCO[1], HABUMUGISHA JEAN DE DIEU[2]

1. Soil Sciences department, School of Agricultural and Rural Development9 SARDAE), College of Agricultural, Animal Sciences and Veterinary Medecine (CAVM) , University of Rwanda(UR)
2. Farmer IPB(Institut Polytchnic of Byumba),Faculty of Agriculture

Corresponding address Author: e-mail: hamudu25@gmail.com, hrukangantambara@ur.ac.rw

ABSTRACT

The influence of dispersed trees on microclimatic conditions, and productivity of maize (Zea mays L.) in an alnus acuminata and markhamia lutea-based agroforestry system in humid highland region of Rwanda was assessed to test the hypothesis that the benefits of shade seen in humid of Gishwati ecosystems may be outweighed by competition for below-ground resources. This study was carried out under trials of ICRAF in partnership with CIMMITY located in the Rwanda humid highland region, part of Gishwati area in North-west of Rwanda, Rubavu district, Nyakiriba sector to investigate impact of agroforestry tree species (*Alnus acuminata* and *Markhamia lutea)* on maize productivity through microclimate and resource use. The study was carried out on 12 plots of 100m^2 (10*10m) designed as follow: tree-crop, crop alone and tree alone for both species with three replicates. Mature trees were used intercropped with maize (PAN691). Soils in each plot were sampled at the beginning of the season and analyzed for nutrients.

To measure impact of agroforestry tree species on maize productivity through microclimate and resource use, in each plots there were established devices such as Tiny tag to record temperature for each thirty minutes, access tubes for measuring soil moisture. Soil nutrients under and away from trees were significantly different with the exception on SOC and on total nitrogen for *Alnus acuminate* which were no significantly different. Maize yield was higher in open fields than under trees with the exception of *A.acuminata* during the best season of 2015 A where rainfall was evenly distributed with more solar radiation. Though soil moisture was always enough through maize growing seasons under and away from trees, higher soil moisture was recorded under *M. lutea* than in open field while it was the reverse for *A. acuminata* and the temperature under *Alnus acuminata* and *Markhamia lutea* was lower than the temperature under open field except at night at day and at night. In general, yield reduction under trees was 10 to 20% as compared to open fields and given the high importance (products and services) of trees on farm in the Gishwati landscape, we conclude that the system with *Alnus acuminata*and *Markhamia lutea* would give higher total productivity than sole cropping system and hence recommend for further promotions of trees in farmers ‘fields.

Key words : Alnus Acuminata, Markhamia lutea, Landscape, intercropping system, etc

INTRODUCTION

In volcanic highland region of Rwanda, farmers face with several abiotics of constraints that led to decrease the yield of maize. Some examples of major abiotic factors include climatic conditions (temperature, rainfall regimes, and season length) and soil related factors such as fertility, acidity, and susceptibility to erosion. Therefore, microclimatic variation has a major impact on crop performance as extremes affect growth, development and yield in a wide range of species **(Slingo et al., 2005).** Previous studies suggest there are thresholds for temperature and atmospheric saturation deficit, above which physiological and developmental processes and yield become increasingly vulnerable **(Challinor et al.,**

2005; Porter and Semenov, 2005). Air temperature is important as excessively hot conditions during critical developmental stages may greatly reduce yield; thus, temperatures exceeding 30 8C may induce pollen sterility and reduce seed or fruit yield **(Porter and Semenov, 2005).** Maize is considered more susceptible to water stress than other crops because of its unusual floral structure with separate male and female floral organs and the most critical period for water stress in maize is ten to fourteen days before and after flowering, with grain yield reduced two to three times more when water deficit coincides with flowering compared with other growing stages **(Grant et al. 1989)** cited by **Huang (2008**). Grain yield of maize suffering water stress at flowering and during grain fill is highly correlated with kernel number per plant **(Bolanos and Edmeades, 1996)** indicating the importance of adequate water supplies during flowering. In addition to the changing climate, a gradual decline in soil fertility is another major issue which is affecting productivity in upland cropping systems **(Nijamudeen et al., 2004).** The decline of soil fertilty is a crucial problem in highland volcanic soil of Rwanda **(Shoji *et al*. 1993b**). Recently research showed that Soil available phosphorus as macronutrient decrease dramatically associated with soil pH variability from 100mg/kg to 20-40mg/kg and soil pH shift from 8.5 to 5.7 **(Balthazar et al, 1993)**, In additional the highland volcanic soil of Rwanda receive high amount of rain fall **(Busogo Meteorological station 2008),** which resulted in intense Weathering processes and leaching of plant nutrients especially in the form of anions NO_3-, SO_4^{2-} and PO_4^{3-} that are not adsorbed on soil colloid and affected by gravitational water and soil erosion **(Rayar.2008). Stoorvogel and Smaling (1990**) indicated that an average of 660 kg N ha^{-1}, 75 kg P ha and 450 kg K ha^{-1} have been lost during the last 30 years from about 200 million hectares of cultivated lands in 37 countries of Sub-Saharan Africa, include Rwanda. Thus, this may have led to increased reliance on inorganic fertilizers by the farmers. Consequently, the cost of production, land degradation and ground-water pollution would increase. Thus, practices aimed at increasing the organic matter content of the soil are recommended to arrest the decline in soil fertility and ensure long-term sustainability. One benefit of increasing trees on farms would be an increase in soil organic carbon (SOC) pools which is a good indication of soil fertility **(Konare et al., 2010).**The introduction of agroforestry practices was reported to be a sustainable solution to keep crop production high while conserving trees on farm. To meet growing demands for food and fuel while controlling soil erosion, farmers in Rwandan highlands have adopted land use practices that produce both food (e.g maize) and energy (e.g *Alnus acuminata* and *Markhamia lutea*) to promote sustainable use of resources. Shade from overstorey trees may ameliorate microclimatic conditions for understorey crops, increasing growth and productivity **(Gregory and Ingram, 2000).** However, the success of any intercropping depends on the balance of positive (facilitation) and negative (competition) interactions between the components (Vandermeer, 1989). There is a limited knowledge on this balance for maize intercropped with *A.acuminata* and *M. lutea* in the volcanic highlands agro-ecological zone (AEZ). This research was to evaluate the possible direct impact of the two most prominent trees in the region on maize where crop production is mainly limited by low radiation, low temperature and soil erosion threats.

MATERIALS AND METHODS

Site description

The study was carried out in ICRAF Rwanda trials located in western province of Rwanda, Rubavu district, Nyakiriba sector in Gikombe cell. Altitude from 2,500 m to 1.900 m even below 1,600 m. This place is located in the agricultural zone of the Birunga groups which is made by the volcanic soil, andosol, soil order of soil taxanomy) and is located at29^0 23’48.9’’ E longitudes and between 1024’57.6’’ and 1040’36.2’’ S latitude. In this agriculture zone there is a regular distribution of rainfall, which is varying between 1,300 and 1,600 mm and fertile soils create favorable conditions for agricultural production.

Experiment design and data collection

The field experiment led out in random completely block design (RCBD with three replication and three treatments organized in this way: tree-crop, crop alone and tree alone. size was $100m^2$ (10*10m) for each plot.

Soil sampling was taken before planting at the beginning of the long rainy season, and was collected under the canopies of each selected tree in each farm (plot). Through Zigzag was used as sampling technique by using auger to sample from 0-20, 20-40, 40-60cm depth and have one composite sample for

November. 2016. Vol. 7, No.1 ISSN 2311 -2476
International Journal of Research In Agriculture and Food Sciences

http://www.ijsk.org/ijrafs.html

each plot for the study of maize productivity and effect of tree species on that productivity.

Soil moisture content measurement (water) using Probe

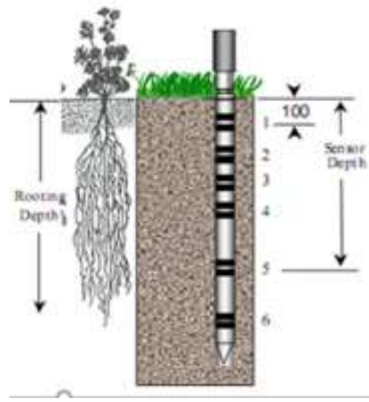

Figure 1:PR2 Soil Moisture Profile Probe. Figure 2: Access tube of PR2 Soil Moisture Profile Probe

Soil moisture probe is the system that enables to measure or to record soil water content with such ease and flexibility. Install an access tube into the soil, insert the PR2 Profile Probe and press the HH2 (Read) button to display instantaneous readings, or connect the PR2 to a data logger (DL6 or DL2e) and leave the system to record soil moisture changes over time.

The relation between the measured property and soil moisture must be calibrated and may vary depending on soil type. Reflected microwave radiation is affected by the soil moisture and is used for remote sensing in hydrology and agriculture. The purpose of measuring soil water content is to see how tree conserve soil moisture by shading, and to see how maize crops located near from tree take advantage of this shade for this reason we used to measure soil water content on areas near from a tree termed B and soil water content on area far from tree termed A and on area without a tree termed C.

Probe (B) measure soil water content at one hundred centimeters (100 mm), at two hundred centimeters (200 mm), at three hundred centimeters (300 mm), at four hundred centimeters (400mm), at six hundred centimeters (600 mm), and at a thousand centimeters (1000 mm) for each area. here for those two area they have grown a single variety of maize to assure that except interaction of crops and tree contribute to crop health other thing such as crop variety are held constant.

Measuring wind temperature by using tinytag

Figure 3:Tinytag for measuring field air temperature

November. 2016. Vol. 7, No.1 ISSN 2311 -2476
International Journal of Research In Agriculture and Food Sciences

http://www.ijsk.org/ijrafs.html

A tiny tag is an electronic device for monitoring temperature, humidity on farm, it records data every 30 minute,

Tinytag Explorer, Windows software are used to configure, offload and analyze data from tinytag. The software is provided as a site license and can be bundled with the appropriate download cable for data accessing.

Tinytag were established in the farm to record temperature data at every 30 minutes, in the field a tinytag is installed at a place near a tree secondly at a place far from a tree and at a place where there is no tree for every plot in order to compare how the temperature differ from zone A; B; and C

Cumulated radiation during maize growing seasons : an integrated sensor suite and recorded hourly variations of radiation was installed near the field.

In the laboratory, soil samples were air dried, crushed, sieved into different fractions (2mm and 0.5mm diameter) and following chemical and physical analyses were carried out : **pH** water was determined using electrode method. **Soil organic carbon** by Walkley and Black method. **Total nitrogen** by digestion and distillation techniques and titrating using Boric acid. Hence the concentration of mineral Nitrogen was obtained by calculating the concentration of Base (NaOH) used in titration. Available Phosphorus was extracted with the method of Bray and Kurtz (1947) and subsequently U.V spectrophotometer and Soil texture was determined using hydrometer method. All parameters were analyzed using protocols and methods from the Research Laboratory of the University of Rwanda CAVM.

Data analysis

The data collected from field trials were entered in Microsoft Excel and analyzed using GenStat (4th edition) software. These data were analyzed statistically using two-way analysis of variance (ANOVA). Means were separated using Duncan test and F-protected least significant difference (F-protected LSD) .

RESULTS

1. Soil nutrient and texture analysis

Initial soil nutrient status and soil texture of experimental sites are presented in table 1.

Table 1. Soil characteristics of the site at the beginning of the experiment

Plots with and without tree	**Depth cm**	**pH (water)**	**SOC_ %**	**% N**	**Avail P.ppm**	**% clay**	**% silt**	**% sand**
Alnus	0-20	6.0	3.9	0.40	24.2	12	26	62
.	20-40	6.1	3.9	0.39	24.5	12	24	64
	40-60	6.2	3.6	0.38	21.5	11	21	68
No Alnus	0-20	6.2	3.9	0.39	17.6	10	27	63
	20-40	6.2	4.1	0.42	16.9	12	26	63
	40-60	6.3	3.7	0.39	16.6	10	21	69
SED		*0.03*	*0.05*	*0.005*	*0.7*	*0.6*	*0.8*	*1.1*
Markhamia	0-20	5.9	5.8	0.57	23.6	9	23	68
	20-40	6.0	5.6	0.59	22.8	8	22	70
	40-60	6.0	5.3	0.56	17.7	8	21	71
No Markhamia	0-20	5.9	5.6	0.50	13.1	9	26	65
	20-40	6.0	5.5	0.55	11.8	9	24	67

	40-60	6.1	5.0	0.48	10.4	8	16	76
SED		0.03	0.05	0.05	1 .15	0.3	1.4	1.6

SED: Standard errors of differences of mean

Soil pH value. There was no a significant (p >0.05) difference among locations in soil pH under and away for both species. And Tree-Species were not significantly different respective at p = 0.057 and LSD=0.1434 for *Acuminata*. While p =0.423 and LSD=0.1434 for *M.lutea* was found. Soil pH values varied from up to depth under all species. 6.0 to 6.2 under alnus; 6.2 to 6.3 no alnus, 5.9 to 6.0 marhkamia and 5.9 to 6.1 no makhamia. In general was observed that there was increased soil pH values through the depth

Soil phosphorus available. For both agroforestry species results under and away both agroforestry species showed that there was significant difference (p < 0.05), ANOVA showed that all treatments were significant different (p =0.015, LSD=3.3) for *A.acuminata* and (p =0.014, LSD=4.9) for *M. lutea*.

Organic carbon. The results from all plots (all species) have shown that soil organic carbon was not significantly different (p > 0.05) within depths under and away from trees

Total soil nitrogen. Results from table one showed that there is no significant difference (p > 0.05) within depths and mean values of total nitrogen for *Alnus acuminata*, whereas for *markhamia lutea* results showed a significant difference at p<0.05, by the ANOVA; for *A.acuminata*, the p: 0.478 and LSD : 0.049, and p: 0.034 and LSD : 0.051 for *M. lutea*

2. **Soil moisture content in the agroforestry plots**

The status of the soil moisture content at one meter from a tree, three meters from trees and on open field (control) field were measured in both season (2015A and 2015B) during the growing seasons and averages are presented in figure 1 below.

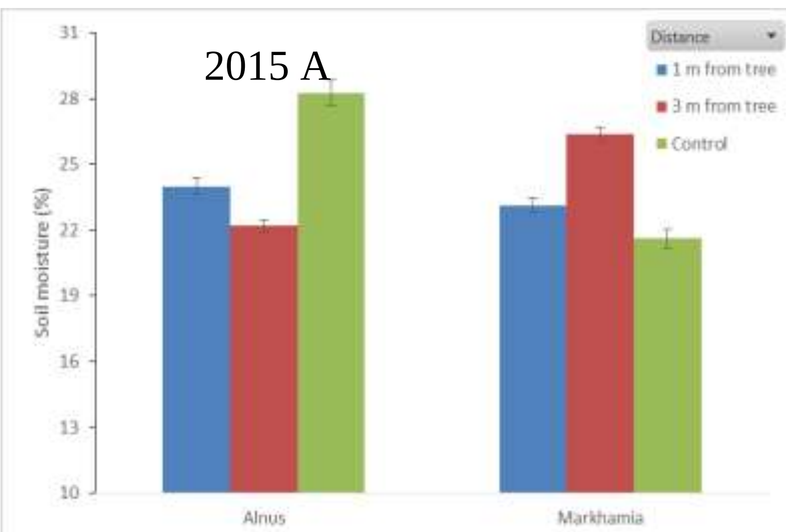

Figure 1: Average soil moisture measured every two weeks throughout the season 2015 A. Error bars represent the standard error of means.

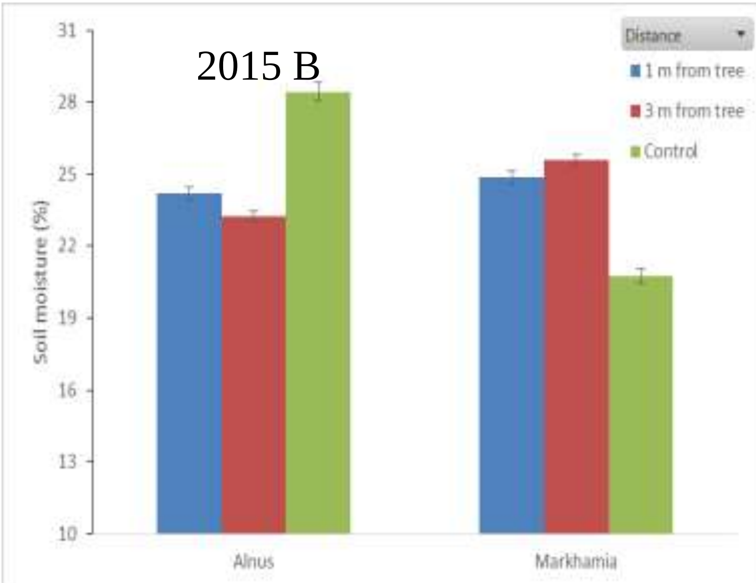

Figure 2: Average soil moisture measured every two weeks throughout the season 2015 B. Error bars represent the standard error of means.

3. Cumulated rainfall during growing seasons

The rainfall patterns of the seasons of investigation differed significantly, in 2015; there was higher rainfall during season B than during season A.

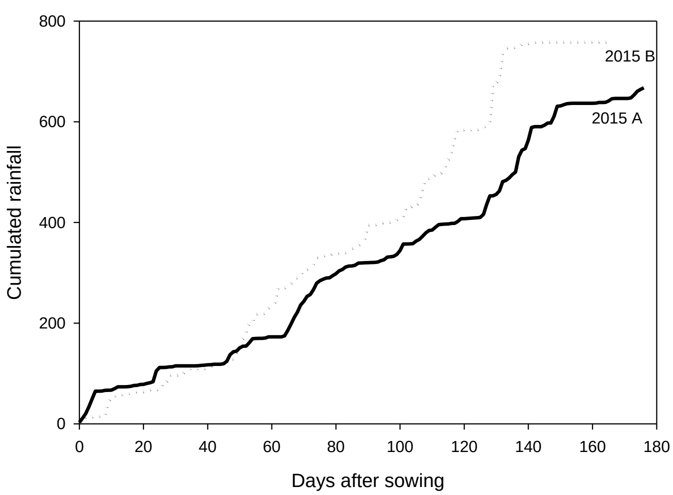

Figure 3: Cumulated rainfall during growing seasons at Gishwati site.

November. 2016. Vol. 7, No.1 ISSN 2311 -2476
International Journal of Research In Agriculture and Food Sciences

http://www.ijsk.org/ijrafs.html

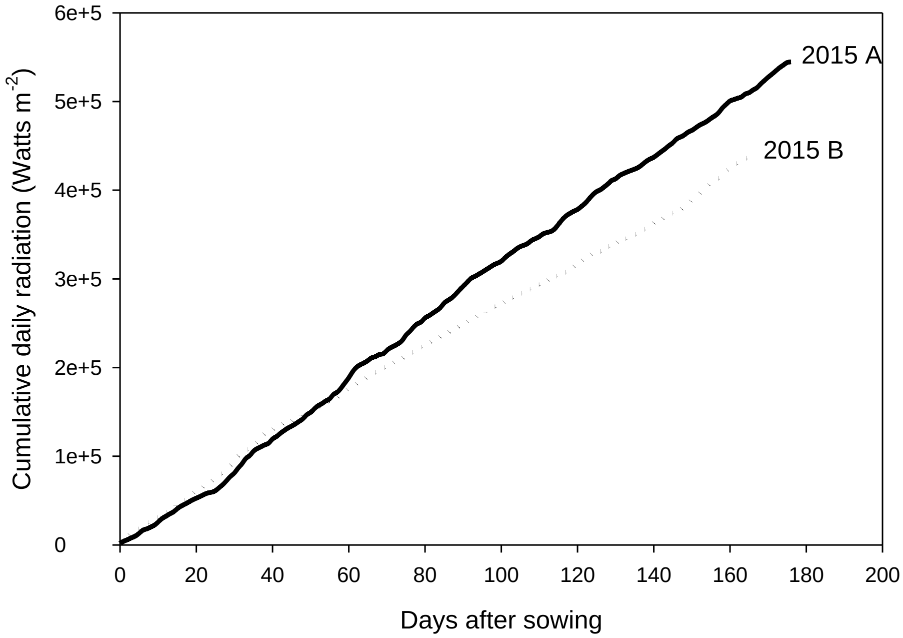

Figure 4: Cumulated radiation during maize growing seasons at site.

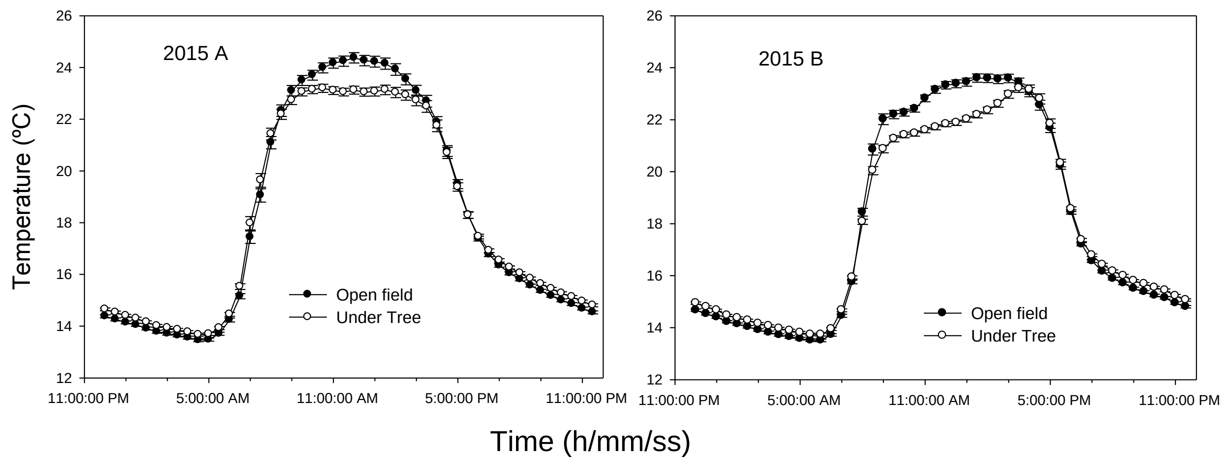

Figure 5: average temperature under Alnus acuminata, Markhamia lutea and open field (control) for both season 2015A and 2015B.

5. Yield

Maize yield (tones/ha) under (at 1m from a tree) and away (3mfrom tree) at each direction *Alnus acuminata*, *Markhamia lutea* and for open field(control) are presented figure.

November. 2016. Vol. 7, No.1 ISSN 2311 -2476
International Journal of Research In Agriculture and Food Sciences

http://www.ijsk.org/ijrafs.html

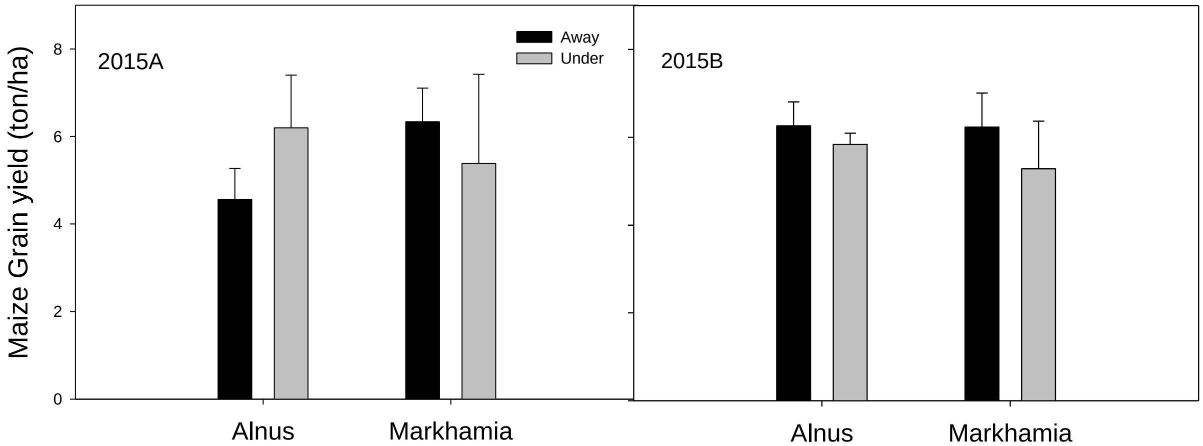

Figure 6:Maize grain yield response under Alnus acuminata, Markhamia lutea and open field are presented, Error bar represent standard deviation

DISCUSSION

Soil chemical and physical parameters

Soil pH

Results showed soil under and away *alnus acuminata* were slightly acidic whereas plots under *markhamia lutea* were moderately acidic. According to Bruce and Rayment (1982**)** when plant roots uptake nutrients, there are release protons and this may overtime contribute in the lowering of soil pH.

Available phosphorus

The available phosphorus decreased from top soils to deeper horizons. It would therefore be assumed that both species have contributed to soil fertility through nutrients recycling. According to FAO, (2009) trees can increase top soil nutrients through nutrient cycling from tree litter fall, tree cover which prevent soil from direct rain drop impact and according to Van Noordwijk et al,(2011) this may be resulted also due to improvement of soil physical properties such as porosity or soil air that means the greater the soil porosity, the higher will be infiltration which reduce runoff and leaching of soil nutrient; this may be resulted also due to shading effect which have reduced temperature that slow mineralization and increase soil water status that is positively correlated with phosphorous availability (Radersma,2002)

Soil Organic carbon

Since the soils in the site were andosols from volcanic materials, they had higher soil carbon and hence overriding the tree effects. (Verdoodt and Rast,2003)

Total nitrogen

According to the norms of interpretation of Okalebo (1991), the total nitrogen was relatively high for all plots.

Physical soil analysis: In general, Soils in Gishwati were classified as sandy loam in Gishwati. As expected, the mollic andosol from the volcanic highland had a medium pH. The top layer had more nutrients than the deeper layers.

In the high rainfall site of Rwanda (Gishwati), the effect of *M. lutea* and *A. acuminate* on maize was investigated. Soil nutrient data, Weather data, soil moisture, air temperature, soil were measured at regular intervals while maize yields were recorded at harvesting. Findings are discussed below.

2.Soil moisture content

The status of the soil moisture content measured during the growing is presented in figures 4 and 5, at a distance of 1m from tree means near tree, 3m from tree and for open field (control).

a) The soil moisture status in *Alnus acuminata* plots

For *Alnus acuminata* plots, the average soil moisture status for both seasons was higher for open field (control) than in *Alnus acuminata* plots (at a distance of 1m from tree and 3m from tree), according to (NFTA, 1994) and Simone& Ong, (2003), trees can decrease soil water contents by their own water use,

International Journal of Research In Agriculture and Food Sciences

http://www.ijsk.org/ijrafs.html

or by interception of rain where interception losses decrease soil water inputs under the trees. However, this decrease in water input to the soil is only slightly larger than evaporation reductions under canopies, which decrease soil water losses under the trees, in addition to that, *Alnus acuminata* is a fast growing agroforestry species which requires a high water and nutrient uptake which makes this tree to be a high water use tree which would have reduced soil moisture observed under it.

b) **The soil moisture status in *Markhamia lutea* plots**

For *Markhamia lutea* plots, average soil moisture status was higher on *Markhamia lutea* plots than in open field. On access tube located at a distance of three meters, probe PR2 has shown a higher moisture status than on access tube located at 1m from a tree, this was due to fact that markhamia lutea has a low water use through it slow growth rate which requires less water use. In fact, Trees can affect soil water contents in different ways; they can increase soil water content by decreasing soil evaporation. According to Simone& Ong, (2003), root length density distribution is a main determinant of soil water content distribution in the soil volume near trees. (Simone Radersma &Chin K. Ong, 2003).Root and crown functions are the driving forces determining the severity of tree crop interactions. Sap flow studies have highlighted the capacity of tree roots to alternate activities such as water uptake from one part of the root system to another, in response to changes in soil profile moisture content

3. Air temperature under tree canopy and in open field

During the growing season, Tinytag measurement shows the air temperature under and outside tree canopy, the results presented in figure 8 shows that the temperature under both *Alnus acuminata* and *Markhamia lutea* was below the temperature found in open field (without tree) for whole growing season due to shading effect by tree canopy, Lott et al. (2009). In this studies found similar results except at 5:00 PM to 6:00 AM where results show that under tree, the temperature was higher than in open field due to the blanket effect of trees. According to Hikosaka et al (2016) for a lower sun most canopies will reflect a slightly larger fraction and for a higher sun they will reflect a slightly smaller fraction this may be being resulted due diffusion of radiation that is intercepted by leaves which leads to exchanges of sensible and latent heat with the atmosphere by leaves and soil which are the principal energy inputs to the atmosphere over land, balanced in the long term by thermal infra-red (TIR) emissions to space. The overall phenomena result in cooler temperature under trees (shade effect) during day time but wormer temperatures (blanket effect) in night time.

4. Yield

Maize grain yield under and away from *A. acuminate* and *M lutea* for two consecutive seasons at Gishwati. Data are means of three replicates (± s.e). For a given tree species, different letters indicate a significant difference by LSD at 5% level.

Alnus acuminate had a positive effect on maize yield during 2015A season, while it had no significant impact (positive or negative) in maize yield during the 2015B season. This implies that rainfall distribution and higher radiation influence the net effect of competition and facilitation between *A. acuminate* and maize: when water is not limiting, the net effect may be facilitation (perhaps because of N fixation by *A. acuminate*) whist it may be neutral when water is limiting.

CONCLUSION

This study was to evaluate effect of Alnus acuminata and markhamia lutea based agroforestry system on maize productivity in Rwanda in humid of volcanic highland region at Nyakiriba watershed site in trials of ICRAF partnership with CIMMITY. The results showed these species, bothn significantly difference p= 0.001 on soil moisture, soil essential nutrients and soil carbon on growth and yield of maize

the soil moisture status under *markhamia lutea* and*Alnus acuminata* was higher than in open field especially in soil upper layer due to lower evapotranspiration caused by tree canopy shading while markhamia is known to have a lower water use regime. The temperature under both *Alnus acuminata* and *Markhamia lutea* was below the temperature found in open field (without tree) for whole growing season due to microclimate created by tree canopy or shading effect.

The soil organic carbon was high in the andosols investigated and hence neutralizing the effect of trees. Available soil phosphorus across depths and mean value on Available phosphorus under markhamia was significantly higher than away (p<0.05). Higher amount of available Phosphorus was on top soils than in deeper horizons proving that markhamia in situ litter may have contributed in nutrients improvement.

acuminate had a positive effect on maize yield during 2015A season, while it had no significant impact (positive or negative) on maize yield during the 2015B season whereas *Markhamia lutea* had no significant in maize yield. We found that in season 2015A the maize yield under *Alnus acuminata* was 6.3 tons/ ha and outside canopy was 4.2 tones/ha, respectively and also under *Markhamia lutea* under tree canopy yield was 6.4 tons/ha and 5.8 outside canopy while in season 2015B yield under *Alnus acuminata* was 6.2 tons/ ha and outside canopy was 6.5 tones/ha,respectively and also under *Markhamia lutea* under tree canopy yield was 5.3tons/ha and 6.1 outside canopy. In general, yield reduction under trees was 10 to 20% as compared to open fields and given the high importance (products and services) of trees in the Gishwati landscape. Thus, we conclude that the system with trees would give higher total productivity than sole cropping system and hence recommend for further promotions of trees in farmers ‘fields.

REFERENCES

1. **Ayachi, M.**(2006). the bugesera agricultural development support project. agriculture and rural development department ex-ocar.
2. **Balthazar,M. M., Shigeru,A. and Nobuhide, F. (1993).** Characterization of Volcanic Ash Soils In South-Western Tanzania: Morphology, Physicochemical Properties, and Classification. Dep. of Soil Science, Fac. of Agriculture, Sokoine University of Agriculture. Japan International Research Center for Agricultural Sciences
3. Bolanos J, Edmeades GO (1996) The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. Field Crops Reearches 48, 65-80
4. **CIMMITY**. (2010). The normalized difference vegetation index (NDVI) GreenSeekerTM handheld sensor: Toward the integrated evaluation of crop management. (.. N. Bram Govaerts, Ed.) Mexico: (K.U.Leuven) .
5. **CIMMITY.** (1999). Adoption of Maize Production Technologies in the Lake Zone of Tanzania. (R. K. January Mafuru, Ed.) Mwanza, Tanzania.
6. **Eike, L**. (2016). Field-scale modeling of tree–crop interactions: Challenges and development needs. Agricultural Systems, 51–69.
7. **FAO**. (1980). Improvement and production of maize, sorghum and millet (Vol. 2). Rome, Italy: Food and agriculture organisation of the united nations.
8. **Friesen, D. K. and Palmer, A.F.E**. (2002). Maize Productivity in the New Millennium. Proceedings of the Seventh Eastern and Southern Africa Regional Maize Conference. Nairobi Kenya: CIMMYT Maize program and Kenya Agricultural Research Institute.
9. Gregory, P.J., Ingram, J.S.I., 2000. Global change and food and forest production: future scientific challenges. Agric. Ecosyst. Environ. 82, 3–14.
10. Grant FR, Jackson BS, Kiniry JR, Arkin GF (1989) Water deficit timing effects on yield components in maize. Agronomy Journal81, 61-65
11. **Huang,R.; Birch ,C. J. and George, D.L.** (2006). Water use efficiency in maize production – the challenge and improvement

strategies. 6th triennial conference 2006. Maize association of australia.

12. **Busogo Meteorological station, (2008),** Farmer's diary Irish potato. Production 278-280 P. National Institute of Statistics of Rwanda, (NISR).Survey report, (2008)
13. **Nair. P.K.R**. (1989). Agroforestry systems in the tropics (Vol. 31). Boston/London: Kluwer academic publishers.
14. **Ong, C.K.; et al.** (2002). Tree–crop interactions: manipulation of water use and root function. Agricultural Water Management, 171–186.
15. Porter, J.R., Semenov, M.S., 2005. Crop responses to climatic variation. Philos. Trans. R. Soc. B 360, 2021–2035
16. **Radersma,S.;and Ong**, **K. C.** (2003). Spatial distribution of root length density and soil water of linear agroforestry systems in sub-humid Kenya: implications for agroforestry models. Forest Ecology and Management, 77–89.
17. **Radersma, S.** (2002). Tree effects on crop growth on a phosphorus-fixing Ferralsol. Wageningen: Wageningen University.
18. **Sigmund, R and Espig,G**. (1991). The cultivated plants of the tropics and subtropics. Germany: Institute of agronomy in the tropics and subtropics. BIBLIOGRAPHY \l 1033
19. Tijan**, F.O.;Oyedele, D.J, & Aina, P.O. (2008)**. Soil moisture storage and water-use efficiency of maize planted in succession to different fallow treatments. Internation agro-physics, 22, 81-87.
20. Slingo, J.M., Challinor, A.J., Hoskins, B.J., Wheeler, T.R., 2005. Introduction: food crop in a changing climate. Philos. Trans. R. Soc. B 360, 1983–1989.
21. **Stoorvogel, J. J. and Smaling, E. M. 1990**. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983 - 2000. Report No. 28, Vol. 1 - 4. Winand Staring Centre, Wageningen, the Netherlands.
22. **Verdoodt, A. and Van Ranst, E.** (2003). Land Evaluation for agricultural product ion in the tropics. Belgium: Ghent University Laboratory of Soil Science.
23. **Yamoah, C. F.; James and Burleigh, R.** (2005). Rwanda Farming Systems Research Program. Kigali Rwanda: The University of Arkansas, Fayetteville(International Agricultural Programs).