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Response of Sorghum-groundnut to Row Arrangement and Orientation under Nominal Nitrogen Management

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Authors' contributions

This work was carried out in collaboration between all authors. Author JST originated and implemented the study and participated in writing the manuscript. Author SM managed the study, searched for literature and did data analysis. Authors CO, JPE and PLW collected data and participated in manuscript development. All authors read and approved the final manuscript.

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ABSTRACT

Aim: A study was conducted in eastern Uganda to rationalise sorghum-groundnut mixtures through manipulation of row arrangement and orientation, under nominal N management.
Study Design: Treatments included row arrangements, v*iz*. alternating 1:1 (single rows) and staggered 2:2 (double rows); row orientation *viz*. north-south and east-west; and N application, *viz.* 0 and 40 kg ha^{-1}. Treatments were laid down in a randomized complete block design, in a split-split plot arrangement. Nitrogen rate was the main plot, row orientation as subplot and row arrangement as sub-subplot.

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Place and Duration of Study: The study was conducted in eastern Uganda for two cropping seasons (2010b-2011a).

Methodology: Sorghum (Sekedo variety) and groundnut Red beauty variety (*Emoit*), were the component intercrops. Measurements included plant height, grain yield, solar radiation interception and intercropping financial advantage. Light interception was determined using a digital Lux light sensor (Lutron Model: Lx-101). The light available to the under storey intercrop was computed as a fraction to the total available (ambient) PAR. The data collected were analysed using GenStat software Version 11, and significant treatment means were separated using LSD at 5% probability level.

Results: Staggered double rows gave better groundnut grain yield irrespective of row orientation and N regime. The E-W row orientation resulted in a greater groundnut yield by up to 50%, than those facing N-S. Sorghum yield, however, was slightly increased by N rate, but not by row orientation and arrangement. Groundnut rows oriented E-W intercepted more solar radiation than those in the N-S direction, in both alternate single and double row arrangements.

Conclusion: The staggered double rows, oriented east-west and subjected to application of 40 N kg ha^{-1} is technically and financially the superior management option for sorghum production in eastern Uganda.

Keywords: Nitrogen; solar radiation; Sorghum bicolor; Arachis hypogea.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is among the most important cereal crops worldwide, feeding over 500 million people [1]. Global production is estimated at 60 million metric tonnes of grain [2]. Sorghum is a major staple and food security crop in sub-Saharan Africa (SSA), where it has proved versatile under various biophysical stresses, especially in the arid and semi-arid environments [3]. In Uganda, sorghum is a major staple cereal crop, ranked third after maize (*Zea mays* L.) and finger millet (*Eleucine coracana* L.) [4]. Its production in the country is estimated at 300,000 metric tonnes annually [5]. It is gradually replacing finger millet due to the latter's heavy weeding labour requirements [6]. Sorghum is largely intercropped with other legume crops such as common beans (*Phaseolus vulgaris* L.), cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogeal* L.) [6]. Elsewhere, sorghum is reportedly more productive when intercropped with legumes [7]; however, information regarding optimum crop mixtures and associated financial benefits is invariably unavailable for various agro-ecosystems in Sub-Saharan Africa.

In Uganda, the scientific basis for sorghum-legume intercropping is either minimal or lacking [8]. This is, especially so for crops like groundnut (*Arachis hypogea* L.), which is a typical legume intercropped with sorghum. Although average global groundnut yield stands at 1,520 kg ha^{-1} [9], the yield in Uganda is barely 800 kg dried pods ha^{-1} on-farm [10], implying need for urgent intervention. Groundnut is a staple and revenue earner for the small-scale farmers in Uganda, especially in the frequently drought stricken eastern and northern Uganda. Perhaps, simple optimisation of resource capture through spatial field manipulation, involving row orientation and arrangement of sorghum-groundnut intercrops could significantly result in yield increases within the crop mixture, with little or no extra investments [11].

Resources of particular concern in crop mixtures in Uganda are solar radiation, especially the photosynthetically active radiation (PAR) and soil nutrients (especially N). Solar radiation capture varies greatly by geographical location, time of the year, intercrop plant morphology, and the soil water and fertility resource base. This nesting of bio-physical conditions, thus suggests that non-conditional extrapolation of findings and their associated interventions may have limited application.

Along the tropics, especially the East African region, it has *hitherto* been assumed that solar radiation is not a limiting factor in crop productivity. However, with the recent weather alterations by the global climate change, it is imperative that row orientations are brought back in the research limelight.

The amount of photosynethetically active radiation (PAR) intercepted by leaves greatly depends upon inter-row spacing, foliage architecture photo-exposure to both intercrops. Erectophile foliage structure intercepts and utilises light better than planophiles, because of the formers' elevated light saturation points [12]. They also permit light penetration to understorey crop in the mixture. In addition, erectophiles (cereals or legumes) respond to fertility inputs more than planophiles [13]. Furthermore, even though intercropping usually includes a legume, applied nitrogen often confers some benefits to the system as the cereal component depends heavily on nitrogen for maximum yield [14]. Overall, however, innovations related to intercropping must be assessed for both technical and financial net returns to investment. This study was conducted to evaluate systematic technical and financial benefits from integration of row arrangements and orientation, together with modest nitrogen application in sorghum-groundnut intercrop in eastern Uganda.

2. MATERIALS AND METHODS

2.1 Site and Soil Sample Analysis

The experiment was conducted during the second rains of 2010 and the first rains of 2012 in Soroti district in eastern Uganda, located at 1° 30' and 33°30' E. The area is considered to be semi-arid, though with a bi-modal rainfall pattern. Its annual mean rainfall ranges from 800 to 1200 mm, and annual mean temperatures of 16-30℃ [15]. The soils are generally sandy and low in available P and N [16,17]. Specifically, the site soil had the following properties: pH in water = 6.2, organic matter = 3.6%, Organic N = 0.17% and Bray 1 extractable P = 3.5 mg kg^{-1}.

2.2 Treatments and Experimental Management

The treatments included: (i) pure stands of sorghum and groundnut, (ii) two row arrangement, alternating single rows (one row for sorghum: 1 row for groundnut) and alternate double rows (2 rows for sorghum: 2 rows for groundnut; (iii) row orientation, east-west (EW) and north south; and (iv) fertiliser rates: 0 and 40 kg N ha^{-1} in form of urea. Phosphorus was applied to all plots at 22.5 kg P ha^{-1}, as single super phosphate, to obviate its limiting effect.

The experiment was laid out in a random complete block design (RCBD), in a split-split plot arrangement. Nitrogen rate was the main plot, row orientation as subplot and row arrangement as sub-subplot. The treatments were replicated three times in plots of 7 m by 31 m (main plot) and 7 m by 7 m (sub-plots). Sorghum, variety Sekedo, and groundnut (Red beauty) locally known as Emoit), were the intercrop materials used. Sekedo is known to be drought resistant, matures in 105 days and has a yield potential of 5 t ha^{-1}. Red beauty is bunchy, with erect branches. It matures in 90-100 days, with a yield potential up to 2500 kg kernel ha^{-1} [10]. Both crops were planted using the recommended pure stand spacings of 60 cm by 20 cm [10], giving plant densities of 408 $plot^{-1}$. The pure stand population densities were maintained for each crop component in the intercrop.

2.3 Measurements

Parameters assessed included plant height, grain yield, solar radiation interception and net financial returns to investment. Plant height was determined using a tape measure, on four randomly selected plants from within 4.2 m x 4.2 m in the central area of each plot, for each crop species. The heights for the four plants were averaged and the resulting value was considered for further statistical analyses. Net financial returns to investment were assessed using the partial budget procedure [18].

Light interception by the upperstorey (sorghum) and understorey (groundnut) crops in the photosynthetically active radiation (PAR) ranged from 400 to 730 µm. Light interception was determined using a digital Lux meter (Lutron Model: Lx-101) at 50% booting for sorghum daily up to physiological maturity of sorghum (65 days after planting). Light measurements began at 6:30 am, and subsequently at 2 hourly interval starting at 8:00 am up to 18 hrs. The light sensor eye was vertically placed 30 cm above the sorghum (upper storey) for ambient light reading. Four readings were taken from above the legume in diagonals from within each quadrant of 4.2 m x 4.2 m, located centrally in each experimental plot of 7 m x 7 m. The understorey light interception was referenced against incident light values (ambient) recorded 30 cm above sorghum in each quadrant. The light available to the under storey intercrop was computed as a fraction to the total available (ambient) PAR. The measurements were in electronic volts (EV) prior to conversion into lux using the manufactures conversion table. The lux values across seasons were then pooled and used to compute for the deviation (percent) from the ambient values, resulting from the intercrop canopy shade effect.

2.4 Data Analysis

The data collected were pooled across seasons and analysed using GenStat software Version 8 and significant treatment means were separated using Fisher's Protected Least Significant difference (LSD) at 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Sorghum Plant Height

There was no significant treatment effect (P = 0.05) on sorghum plant height in all treatments (Fig. 1). This can be explained in part by the unhindered access to solar radiation. Sorghum being an upper storey in the sorghum-ground nut intercrop, and given that recommended spacing was maintained in the study plots, it is unlikely that sorghum plant access to light was affected by agronomic manipulations. On the other hand, the indigenous soil N might have been enough for sorghum vegetative growth.

3.2 Sorghum Grain Yield

Grain yield of sorghum in the sorghum-groundnut intercrop without N supplementation was not significantly different from that of the pure stand sorghum counterpart (Fig. 2). This can be attributed to the N sparing effect, which states that in case of low N, the legume resorts to fixing N for its use living its companion to depend on the soil N [19]. Additionally, sorghum being a deep rooter, it is likely that it utilises N from lower soil layer, further reducing the competition with groundnut which is a shallow rooter in the intercrop. Application of N significantly (P=0.05) improved the sorghum-groundnut intercrop. Similar results were reported for a sorghum-groundnut intercrop experiment in semi-arid Sudan [20]. The high yield observed when N was applied could be attributed to the amount of N present for the intercrop compared to no N application.

3.3 Groundnut Plant Height

The more than double increase in groundnut height, in alternative single rows, oriented N-S than in the staggered double rows (Fig. 3), was evidently due to etiolating in the former. This could be attributed to greater shading by sorghum in the alternating single row, which forced groundnut to etiolate in search of light. Etiolating is a phenomenon attributed to abnormal elongation of internodes of shade-affected plants [21]. High Gibberellins levels are highly associated with abnormal growth and, consequently, plant height [22]. Therefore single row alternating is undesirable in sorghum-groundnut intercrop in eastern Uganda. The greater groundnut plant height in the 40 kg N ha^{-1} plots implies that N was a limiting nutrient in the soil.

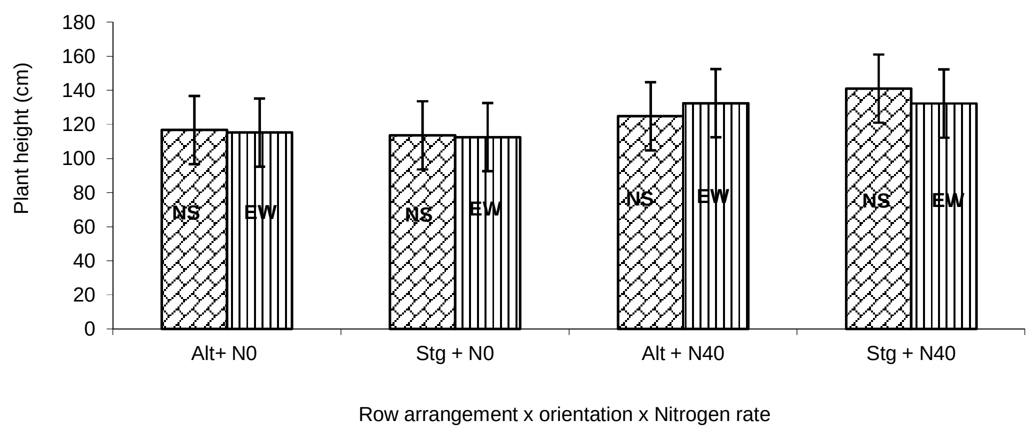

Fig. 1. Effect of row orientation and arrangement, and N application on sorghum plant height at sorghum booting stage (60 DAP) in eastern Uganda

Alt – Alternating single row as; Stg= Staggered double rows; NS = North-south row orientation; EW = East-west orientation; N0 = No applied N and N40 = 40 kg N ha^{-1}

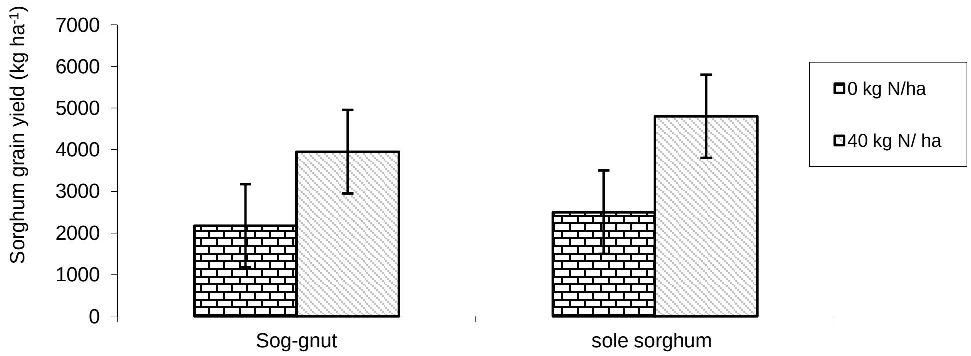

Fig. 2. Effect of legume species and N rate (kg ha^{-1}) on sorghum grain yield in eastern Uganda
Sog = Sorghum; gnut = Groundnut

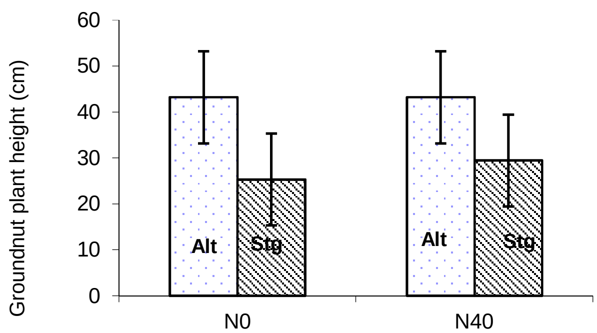

Fig. 3. Effect of nitrogen rate and row arrangement on groundnut plant height at physiological maturity (70 DAP)
Alt = Alternating single rows; Stg = Staggered double rows; N0 = No N applied; N40 = 40 kg N ha^{-1}

3.4 Groundnut Grain Yield

Single row alternation with no N application, gave marginally inferior groundnut grain yield to those of the staggered double row arrangement (Fig. 4). Overall, however, the staggered N-fed E-W groundnut performed best and led to almost double the grain yield of the poorest treatments, the alternating and single, with or without N. As such, in this part of Uganda, it is imperative that the staggered double row arrangement, oriented in the E-W direction is adopted to achieve yield advantages. Nevertheless, the upper limit for staggering the lines still remains to be established, particularly for commercial farmers targeting use of mechanization for field operations.

3.5 Row Orientation and Arrangement

The consistently better performance of the staggered double row (Fig. 4) is irrefutable evidence that access to light is key in the sorghum-groundnut intercrop in this region. Similar findings were reported in western Kenya by [23]. This is further attested by row orientation, with the east-west having a yield edge over north-south orientation. Furthermore, the greater yield with applied N also proved that native soil N supply was insufficient to support the intercrop. Even in the staggered rows, the difference in grain yield was remarkable (nearly 30%). It is, therefore apparent that in order to optimise sorghum-groundnut grain yield in eastern region within sorghum-groundnut intercrops, the staggered double rows, oriented east-west and fed with N should be adopted by farmers.

3.6 Light Interception

The E-W maintained higher light interception at the understorey (groundnuts) levels than its N-S counterparts, even in the twilight regions (Fig. 5). The N-S orientation consistently suppressed groundnut light interception, most seriously in the twilight regions (before 6:30 hrs and after 18:00 hrs). The only exception was in the Zenith (noon) region, whereby the interception response lines converged nearly perfectly with the E-W oriented rows. The twilight regions of N-S affected light interception the most; by nearly 100% in early mornings, and by up to 80% in the evenings. The effect of N application was most prominent in the 0 N rate, for both orientations, whereby light interception was highly suppressed. In other words, N application to the intercrops, under staggered double rows or different row orientations, increases light interception by the understorey crop.

The high light interception in both staggered double rows and alternate single rows, oriented E-W could be attributed to direct rays of the sun permeating through the upperstorey sorghum with minimum throughout the day. On the other hand, the understorey light interception in rows oriented N-S was much more reduced by the sorghum shade. However, between 10:00 and 14:00 hrs (when the sun was at its zenith), groundnuts rows in all treatments intercepted similar amounts of light. During this period the sun is vertical enough to supply even radiation to the understorey crop. The difference in light

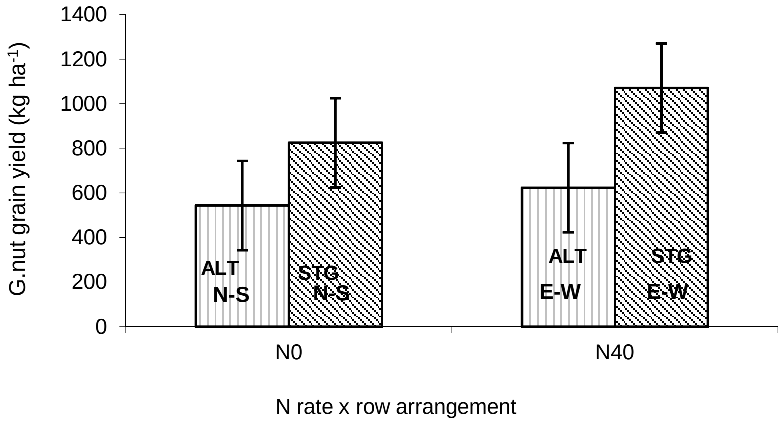

Fig. 4. Effect of N rates and sorghum-groundnut row arrangement on groundnut grain yield
Alt = Alternating single rows; Stg = Staggered double rows; N-S = North-south oriented rows; E-W = East-west oriented rows; N0 = No N applied; N40 = 40 kg N ha^{-1}

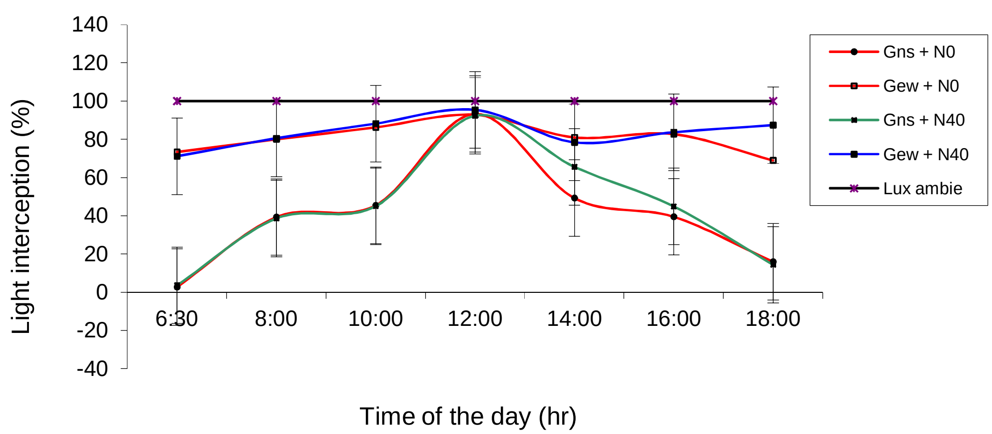

Fig. 5. Diurnal light interception by groundnut under varying sorghum-groundnut row orientation and N rates
G = Groundnut-sorghum intercropping; ew = East-west rows; ns = North-south rows; N0 = No N applied, and N40 = 40 kg ha^{-1}. Zenith is around 12:00 hrs and twilight is before 6:30 and 18:00 hrs

interception and its effect on understorey crop productivity, therefore, can be associated with the twilights. Twilights are light period at 0 time when the sun is within +10 and -10 of the horizontal. This refers to the quality of light at dawn and dusk [24]. According to Attridge [24], twilights are associated with quality light important in exciting the photo electrons resulting in high rate of photosynthesis. The effect is likely to have been more pronounced in the alternate/staggered double rows than the alternate single rows. In general, the high radiation interception effect of the intercrop performance influenced groundnut yield in different row orientation and arrangements.

3.7 Financial Returns to Investment

It is apparent that the net financial effect of N fertilisation was remarkably gainful, irrespective of row arrangement or orientation (Table 1). However, the staggered double rows, accompanied by the E-W row orientation, tended to be superior, though not quite different from the alternating single rows oriented N-S and fed with 40 kg N ha^{-1}.

Table 1. Effect of nitrogen, row row arrangement and orientation on financial returns to investment (United States dollars) of sorghum groundnut intercrops in Eastern Uganda

Nitrogen rate (kg ha^{-1})	Sorghum-groundnut rows arrangement and orientation			
	Single alternate		Double staggered	
	N-S	E-W	N-S	E-W
0	635	620	725	950
40	875	925	1305	1225

N-S = North = South oriented rows; E-W = East-west oriented rows

This study has demonstrated that intercropping sorghum with groundnut is not only technically viable in eastern Uganda, but also more financially beneficial if accompanied by double staggered row arrangement and oriented E-W, and fed on modest quantities of applied nitrogen.

4. CONCLUSION

The study has revealed that inter-seeding in alternate single row patterns leads to reduced sorghum-groundnut yield and financial returns to investment; yet staggering both crop rows improve groundnut yield and the overall performance of the intercrop. In fact, the staggered double rows, oriented east-west and subjected to application of 40 N kg ha^{-1} constitutes the superior management option. In general, light interception is crucial for the understorey crop in the sorghum-groundnut intercrop in eastern Uganda.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAO. Food and agricultural organisation. Monthly bulletin of statistics. FAO Rome, Italy. 1983;6.
2. Nusrat Habib, Ayesha Tahir, Qurat Ul Ain. Current situation and future outlook of sorghum area and production in Pakistan. Asian Asian Journal of Agriculture and Rural Development. 2013;3(5):283-289.
3. Hammer BR, Kirbis AW, Mertz ET, Axtell DJ. Effect of cooking on the protein profiles and *in vitro* digestibility of sorghum and maize. Journal of Agricultural and food Chemistry. 1986;34:647-649.
4. Esele JP, Okelle SE. Current status of sorghum and millets research in Uganda. In: Guiragossain V and Mukulu SZ, (eds). Proceedings of the 6th a Regional Workshop on East African Sorghum and Millets. 20 – 27 July, Mogadishu, Somalia. 1988;318-335.
5. USDA (United States Department of Agriculture). Uganda Sorghum Production by Year; 2014. Available:http://www.indexmundi.com/agriculture/?country=ug&commodity=sorghum&graph=production. (Accessed 10th July 2015)
6. Nyende P. Effect of soil fertility and weed management on the performance of finger millet in eastern Uganda. MSc. Thesis, Makerere University Kampala, Uganda; 2001.
7. Umrani NK, Shinde SH. Intercropping of legumes and oilseed crops in sorghum. Journal of Maharashtra Agricultural University. 1985;10(2):128-133.
8. Sabiiti AG, Nsubuga ENB, Adipala E, Ngambeki DS. Socioeconomic aspects of cowpea production in Uganda a rapid rural appraisal. Uganda Journal of Agricultural Sciences. 1994;2:29-35.
9. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics).

Groundnut (*Arachis hypogaea* L.). Science with a human face; 2015.
Available:http://www.icrisat.org/crop-groundnut.htm
(Accessed 10th July, 2015)

10. Okello DK, Biruma M, Deom CM. Overview of ground nut research in Uganda: Past present and future). African Journal of Biotechnology. 2010;9(39):6448-6459.
Available:http://www.academicjournals.org/AJB
(Accessed July 9th 2015)

11. Woomer PL, Tungani JO. Light availability within an innovative maize-legume intercropping system in Western Kenya. African Crop Science Conference Proceedings. 2003;6:42-46.
ISSN: 1023-070X.

12. Innes P, Blackwell RD. Some effects of leaf posture on the yield and water economy of winter wheat. Journal of Agricultural Science. 1983;101:367-376.

13. Hoad SP, Davies DHK, Topp CFE. What will organic farming deliver? COR. 2006; 117. How to select varieties for organic farming: Science and practice. Aspects of Applied Biology. 2006;79.
Available:http://orgprints.org/10201/1/How_to_select_varieties_for_organic_farming_-_science_and_practice.pdf
(Accessed on 10 June 2015)

14. Ofori F, Stern W. Maize/cowpea intercrop system: Effect of nitrogen fertiliser on productivity and efficiency. Field Crop Research. 1996;14:247-261.

15. Yost D, Eswaran H. Major land resource area of Uganda. A report submitted to USAID by the Soil Management Support Services, Agency for International Development. Washington. D.C., USA. 1990;127.

16. Tigner R. Partial budgeting: A tool to analyze farm business changes. Ag Decision Maker. Iowa State University. Extension and Outreach; 2006.
Available:https://www.extension.iastate.edu/agdm/wholefarm/html/c1-50.html
(Accessed 9th 2015)

17. Tenywa JS, Kidoido M, Nyende P, Kasenge V, Oryokot J, Mbowa S. Prospects and constraints of finger millet production in Eastern Uganda. African Crop Science Journal. 1999;7(4):563-578.

18. Page AL, et al. Methods of soil analysis. Part 2 - chemical and microbiological properties. Second edition. American Society of Agronomy. 1982;167.

19. Giller KE. Nitrogen fixation in tropical cropping systems. 2nd Edition, 2. CAB International, Wallingford Oxon OX10 8DE, UK. 2001;423.

20. Siddig A. Mohamed Ali, Adam A. Mohamed, Ali H. Bahar, Abdulmohsin R. Khairelseed. Effects of sorghum (*Sorghum bicolor* (l) Moench) and groundnut (*Arachis hypogaea* L.) intercropping on some soil chemical properties and crop yield under rain-fed conditions. ARPN Journal of Science and Technology. 2013;69-74. ISSN: 2225-7217.

21. Franklin KA, Whitelam GC. Phytochromes and shade-avoidance responses in plants. Annals of Botany. 2005;96(2):169-175. DOI: 10.1093/aob/mci165

22. Hey RKM, Walker AJ. An introduction to the physiology of crop yield. Longman Group, UK. 1989;292.
Available:http://www.fao.org/wairdocs/ilri/x5488e0.htm

23. Langat MC, Okiror MA, Ouma JP, Gesimba RM. The effect of intercropping groundnut (*Arachis hypogea* L.) with sorghum (Sorghum bicolor L. Moench) on yield and cash income. Agricultura Tropica et Subtropica. 2006;39:2.

24. Attridge TH. Light and plant responses. Edward Arnold (New York). 148 pp. Badescu V. A verification of the atmospheric model proposed by Barbaro et al. for computing direct and diffuse solar radiation. Solar Energy. 1981;26(5): 459-460.

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