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*Full Length Research Paper*

# Agro physiological characteristics of quality protein maize genotypes as influenced by irrigation and plant population in a semi arid Region of Nigeria

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**An experiment was conducted to assess the response of agrophysiological characters of quality protein maize genotypes to plant population under irrigated conditions in a semi arid ecology of Northern Nigeria. Field trials were conducted at the Irrigation Research Station, Institute for Agricultural Research, Kadawa (11° 39'N, 08° 20'E) and 500 m above sea level) during 2007, 2008 and 2009 dry seasons to study the effect of (*Zea mays* L.) genotypes (TZE-W Pop X 1368, EV-DT W99 STR and DMR-ESRW), four plant population (33,333, 44,444, 55,555 and 66,666 plants ha$^{-1}$) and three irrigation scheduling (40, 60 and 80 centibars soil moisture tension) on the growth and yield of quality protein maize. A split plot design was used with combinations of genotypes and irrigation regimes assigned to the main plot and plant population assigned to the sub-plot. The treatments were replicated three times. The study revealed that genotype EV-DT W99 STR recorded significantly higher relative growth rate, crop growth rate and net assimilation rate. Increase in plant population significantly decreased leaf area index and net assimilation rate. Delayed irrigation significantly depressed total dry matter production. Based on the results obtained in this study, it can be concluded that the use of genotype EV-DT W99 STR, at 60 centibars irrigation scheduling and 55,555 plants ha$^{-1}$ had resulted in good agrophysiological characters of QPM at Kadawa.**

**Key words:** Quality protein maize genotypes, plant population, irrigation, agrophysiological characteristics.

## INTRODUCTION

Maize grown in Nigeria has traditionally been conventional maize varieties. With improvements in maize breeding, quality protein maize (QPM), a new class of maize was developed at Purdue University, USA, in 1963. QPM combines the nutritional excellence of Opaque-2 maize (whose protein content is twice that of normal maize) with the kernel structure of conventional maize varieties (Vassal et al., 1993). There is a dearth of research on the performance of QPM genotypes under irrigated conditions in semi arid regions of Nigeria. QPM production is being promoted across Nigeria mainly in areas where it is grown in the wet season. Most QPM genotypes were bred under rain fed conditions. The yield potential in the savanna ecology is higher compared to the wetter (Forest) and drier (Sahel) environments (Kassam et al., 1975) due to adequate moisture, low

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disease incidence, low night temperatures and high solar radiation. With early maturing genotypes developed, production of such QPM genotypes under irrigation is a possibility as moisture supply is not limiting and the ecology's agro-climatological characteristics permit such production. Maize is the agronomic grass species that is most sensitive to variations in plant population. For each production system, there is a population that maximizes grain yield. The importance of plant population as a factor determining growth and yield of early maize cultivars has been established (Gretzmacher, 1979; Zarogiannis, 1979; Bavec, 1988). Maize varieties grown respond differently to various agro management practices especially plant population in the form of different agro-physiological parameters. This variable response is mainly due to differences in agro-physiological parameters such as leaf area index, relative growth rate, net assimilation rate, relative growth rate etc. This study was therefore conducted to study the effect of high plant population on agrophysiological characters of QPM genotypes under irrigated conditions in a semi arid ecology.

## MATERIALS AND METHODS

The study was conducted under irrigation during 2007, 2008 and 2009 dry seasons at the Kadawa Irrigation Research Sub-Station of the Institute for Agricultural Research, Ahmadu Bello University, Zaria. The site is located in the Sudan Savanna ecological zone of Nigeria (11° 39'N, 08° 20'E and 500 m above sea level). The area has a cool dry season that has the north-eastern winds, which are cool and contain dust blown from the Sahara Desert. The minimum temperature ranges between 11 to 18°C in the cool months (November to March) with maximum temperatures of 25 to 40°C in the warmer months (April to October) which is ideal for cultivation of wide variety of crops in the dry season. The soils are, in general, moderately deep and well drained with sandy loam textured surface and sandy clay loam textured subsoil.

The treatments consisted of three QPM genotypes (TZE-W Pop x 1368, EV DT-W 99 STR, and DMR-ESRW) three irrigation scheduling regimes (40, 60 and 80 centibars soil moisture tension) and four plant population (33,333 44,444, 55,555 and 66,666 plants $ha^{-1}$). The experiment was laid out in a split plot design in which a factorial combination of genotype and irrigation scheduling were assigned to the main plot and plant population density was assigned to the sub-plots and replicated three times. Planting was done on February 14, in 2007, February 21 in 2008 and February 17 in 2009 respectively. The inter row spacing was 75 cm whereas the intra row spacing used was 40 cm (33,333 plants/ha) 30 cm (44,444 plants/ha) 24 cm (55,555 plants/ha) and 20 cm (66,666 plants/ha) respectively in order to achieve the desired plant population. The QPM genotypes used for the study were TZE-W Pop x 1368 (open pollinated, white seeded, early maturing, tolerant to *Striga hermonthica,*), EV DT-W 99 STR (open pollinated, white seeded, early maturing, tolerant to *Striga hermonthica),* and DMR-ESRW (open pollinated, white seeded, early maturing, tolerant to *Striga hermonthica* and downy mildew). Furrow method of irrigation was used in supplying water to the crop. Irrigation treatment was imposed beginning from 4 WAS. The irrigation was at 40, 60 and 80 centibars soil moisture tension. A tensiometer was installed at each main plot for the purpose of taking the reading. Weeds were controlled with the use of a pre-emergence herbicide; a mixture of metalachlor + atrazine (2:1) was applied at the rate of 1.5 kg ai/ha (4 l/ha) supplemented by hoe weeding at 6 WAS in the experimental plots and around the field. Fertilizer was applied at the rate of 120 kgN, 26 kgP and 50 kgK per hectare respectively. Half the N and all P and K were applied at two weeks after sowing by side placement 8 to 10 cm away from the base of the plant stands. At 6 WAS, the other half of N was applied by side placement 8 to 10 cm away from the base of the plant stands and followed by irrigation. The following parameters were computed as indicated:

### Leaf area index (LAI)

The product of the length and breadth was multiplied by a factor (0.75) to calculate the leaf area (Watson, 1937). The leaf area obtained from the individual leaves was added and divided by the number of plants sampled to obtain LAI. The leaf area per plant was then multiplied by the number of plants/$m^2$ and divided by the land area covered by the plant (Duncan and Hasketh, 1968).

$$L = \frac{A}{P}$$

Where: L = Leaf area index, A = Assimilatory surface, P = certain ground surface.

### Crop growth rate (g/$m^2$/week)

This was determined at 8 and 12 WAS from the five sampled plants after being oven dried to a constant weight. The following formular was used (Watson, 1952).

$$CGR = \frac{W2 - W1 \times 1}{t_2 - t_1 \quad G_A} = g/m^2/week$$

Where $W_1$ and $W_2$ refer to the whole plant dry weight on two successive times, $t_1$ and $t_2$, $G_A$ refers to land area covered by the plant.

### Relative growth rate (g/g/wk)

This was calculated at 8 and 12 WAS. It was determined after oven drying the sampled plants to a constant weight using the formular; (Fisher, 1921).

$$RGR = \frac{\text{Loge}W_2 - \text{Loge}W_1}{t_2 - t_1} = g/g/wk$$

Where $W_1$ and $W_2$ refer to the whole plant dry weight on two successive times, $t_1$ and $t_2$.

### Net assimilation rate (g/$cm^2$/wk)

This was determined at 8 and 12 WAS. The leaf area of each sampled plant was calculated by measuring the length of each leaf and breadth which was measured from the widest portion of the leaf, then the product of length and breadth was multiplied by a factor (0.75). After that the dry weight of each sampled plant was then determined and the net assimilation rate was calculated using

**Table 1.** Effects of genotype, irrigation scheduling and plant population on net assimilation rate (NAR), crop growth rate (CGR) and relative growth rate (RGR) of QPM genotypes at harvest in 2007, 2008 and 2009 dry season at Kadawa.

| Treatment | Net assimilation rate | | | Crop growth rate (CGR) | | | Relative growth rate (RGR) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2007 | 2008 | 2009 | 2007 | 2008 | 2009 |
| **Genotype** | | | | | | | | | |
| TZE-W Pop X 1368 QPM | 12.68[b] | 13.71 | 14.89[b] | 12.68[b] | 13.71 | 14.89[b] | 155.29[c] | 175.33 | 159.55[b] |
| EV-DT W99 STR QPM | 13.96[a] | 13.74 | 16.56[a] | 13.96[a] | 13.74 | 16.56[a] | 171.33[a] | 168.83 | 172.92[a] |
| DMR-ESRW QPM | 11.70[c] | 14.07 | 15.50[b] | 11.70c | 14.07 | 15.50[b] | 164.15[b] | 162.38 | 160.87[b] |
| SE (±) Significance | 0.17 | 0.20 | 0.36 | 0.17 | 0.20 | 0.36 | 2.30 | 2.99 | 3.43 |
| **Irrigation scheduling (I)** | | | | | | | | | |
| 40 centibars | 12.64 | 13.67 | 15.34 | 12.64 | 13.67 | 15.34 | 164.31 | 164.71 | 170.08 |
| 60 centibars | 12.75 | 13.78 | 15.99 | 12.75 | 13.78 | 15.99 | 163.72 | 169.45 | 173.56 |
| 80 centibars | 12.95 | 14.07 | 15.03 | 12.95 | 14.07 | 15.03 | 170.30 | 169.20 | 177.70 |
| SE (±) | 0.17 | 0.20 | 0.36 | 0.17 | 0.20 | 0.36 | 2.30 | 2.99 | 3.43 |
| **Plant population (P)** | | | | | | | | | |
| 33,333 plants $ha^{-1}$ | 12.85 | 13.95 | 15.65 | 12.85 | 13.95 | 15.65 | 172.18[a] | 171.52[a] | 174.71[a] |
| 44,444 plants $ha^{-1}$ | 12.69 | 13.75 | 15.29 | 12.69 | 13.75 | 15.29 | 161.38[ab] | 173.90[ab] | 161.91[ab] |
| 55,555 plants $ha^{-1}$ | 12.76 | 13.78 | 15.03 | 12.76 | 13.78 | 15.03 | 158.12[b] | 179.25[b] | 162.91[b] |
| 66,666 plants $ha^{-1}$ | 12.83 | 13.89 | 15.84 | 12.83 | 13.89 | 15.84 | 165.68[ab] | 171.52[ab] | 163.52[ab] |
| SE (±) | 0.17 | 0.20 | 0.35 | 0.17 | 0.20 | 0.35 | 2.93 | 3.53 | 4.52 |
| **Interaction** | | | | | | | | | |
| G x I | NS | NS | NS | NS | NS | NS | * | ** | * |
| G x P | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| I x P | NS | NS | NS | NS | NS | NS | NS | * | NS |

Means followed by the same letter(s) within a column and treatment group are statistically similar using DMRT, NS - Not significant, *- Significant at 5%.

the relation or formular (Gregory, 1926).

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1} = g/cm^2/wk$$

Where $W_1$ and $W_2$ are initial and final dry weights. $L_1$ and $L_2$ are the initial and final leaf area indices and $t_2$ and $t_1$ are the length of time interval.

Harvesting was carried out when the cobs have dried enough and the leaf sheath have turned brown in colour. The data collected were statistically analysed using the SAS software.

## RESULTS AND DISCUSSION

The trend of net assimilation rate (NAR) and crop growth rate (CGR) of QPM genotypes is shown in Table 1 and indicate that for both parameters, in 2007 and 2009, genotype EV-DT W99 STR QPM had significantly higher NAR than genotypes TZE-W Pop X 1368 QPM and DMR-ESRW QPM except in 2007 when genotype DMR-ESRW QPM had significantly lower NAR and CGR values respectively. Irrigation scheduling and plant population had no significant effect on both NAR and CGR. Relative growth rate (RGR) was significantly affected by genotype in 2007 and 2009 as shown in Table 1. The result indicate that genotype EV-DT W99 STR QPM had significantly higher RGR than genotypes TZE-W Pop X 1368 QPM and DMR-ESRW QPM except in 2007 when genotype DMR-ESRW QPM had significantly lower RGR values respectively than the other two genotypes respectively. Plant population significantly RGR where plant population of 33,333 plants $ha^{-1}$ had significantly higher RGR values than plant population of 55,555 plants $ha^{-1}$ but was statistically similar to RGR values of 44,444 plants $ha^{-1}$ and 66,666 plants $ha^{-1}$ respectively.

### Total dry matter per plant

The effects of genotype, irrigation scheduling and plant population on total dry matter per plant (g) of QPM genotypes at harvest during the study period is shown in Table 1. The results indicate that genotypic differences significantly influenced dry matter accumulation across the three years of study. In 2007 and 2009, genotype

**Table 2.** Effects of genotype, irrigation scheduling and plant population on Leaf area index (LAI) and Total dry matter per plant (g) of QPM genotypes at harvest in 2007, 2008 and 2009 dry season at Kadawa.

| Treatment | Leaf area index | | | Total dry matter per plant (g) | | |
|---|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2007 | 2008 | 2009 |
| **Genotype** | | | | | | |
| TZE-W Pop X 1368 QPM | 2.80[b] | 2.64 | 3.47[b] | 231.98[b] | 215.48[b] | 375.79[b] |
| EV-DT W99 STR QPM | 3.88[a] | 2.86 | 5.26[a] | 283.25[a] | 267.35[a] | 523.08[a] |
| DMR-ESRW QPM | 2.93[b] | 3.00 | 3.51[b] | 161.71[c] | 276.58[a] | 298.39[c] |
| SE (±) Significance | 0.16 | 0.12 | 0.02 | 11.95 | 13.02 | 21.66 |
| **Irrigation scheduling (I)** | | | | | | |
| 40 centibars | 3.22 | 2.88 | 4.14 | 242.20[a] | 272.50[a] | 432.83[a] |
| 60 centibars | 3.38 | 3.02 | 4.29 | 232.57[a] | 262.75[a] | 410.05[a] |
| 80 centibars | 3.03 | 2.60 | 3.81 | 202.16[b] | 224.16[b] | 354.37[b] |
| SE (±) | 0.16 | 0.12 | 0.02 | 11.95 | 13.02 | 21.66 |
| **Plant population (P)** | | | | | | |
| 33,333 plants $ha^{-1}$ | 3.43 | 3.05[a] | 4.36 | 228.33 | 259.73 | 410.13 |
| 44,444 plants $ha^{-1}$ | 3.17 | 2.95[ab] | 4.01 | 231.54 | 256.96 | 407.25 |
| 55,555 plants $ha^{-1}$ | 3.30 | 2.82[ab] | 4.28 | 219.91 | 250.61 | 393.37 |
| 66,666 plants $ha^{-1}$ | 2.98 | 2.51[b] | 3.69 | 222.79 | 245.24 | 385.59 |
| SE (±) | 0.19 | 0.16 | 0.02 | 8.17 | 9.42 | 14.88 |
| **Interaction** | | | | | | |
| G x I | NS | NS | NS | * | ** | * |
| G x P | NS | * | NS | NS | NS | NS |
| I x P | NS | NS | NS | NS | * | NS |

Means followed by the same letter(s) within a column and treatment group are statistically similar using DMRT, NS- Not significant; *, Significant at 5%.

DMR-ESRW QPM recorded statistically lower TDM/plant than the other two genotypes. In 2008, genotype EV-DT W99 STR QPM recorded significantly higher TDM/plant than TZE-W Pop X 1368 QPM but was statistically similar to DMR-ESRW QPM. This could be due to some inherent genetic and physiological differences that exist between the varieties. Growth characters are genetically controlled and to some extent influenced by the environment. Irrigation scheduling had a significant effect on TDM/plant throughout the course of the study. The result indicates that irrigating at 80 centibars resulted in significantly lower TDM/plant than irrigating at 40 and 60 centibars respectively over the course of the study period. The result indicated that plant population had no significant effect on TDM/plant throughout the course of the study.

### Leaf area index (LAI)

The effects of genotype, irrigation scheduling and plant population on leaf area index (LAI) at 8 WAS during the study period is shown in Table 2. The results indicate that genotype significantly influenced leaf area index in 2007 and 2009. In 2007 and 2009, genotype EV-DT W99 STR QPM recorded statistically higher LAI than the other two genotypes. This could be due to some inherent genetic and physiological differences that exist between the genotypes. Growth characters are genetically controlled and to some extent influenced by the environment. Irrigation scheduling had no significant effect on LAI throughout the course of the study. The result indicates that plant population significantly influenced LAI only in 2008 where plant population of 33,333 plants $ha^{-1}$ had significantly higher LAI values than plant population of 66,666 plants $ha^{-1}$ but was statistically similar to LAI values of 55,555 and 44,444 plants $ha^{-1}$ respectively.

## DISCUSSION

Genotype EV-DTW99STR QPM had significantly higher relative growth rate and net assimilation rate. Genotype TZE-W Pop X 1368 QPM however, exhibited shorter days to 50% tasseling and silking. Genotype DMR-ESRW QPM did not exhibit any superior traits over the other two genotypes. Many workers have reported growth and yield differentials among different maize varieties and genotypes (Hamidu, 1999; Bello, 2001; Ogunbodede et al., 2001; Mani, 2004; Abdulai et al., 2007; Abdelmula and Sabiel, 2007; Sharifi and Taghizadeh, 2009; Badu-Apraku and Fontem-Lum, 2010). Varying irrigation scheduling had significant effects on many growth parameters assessed. The results of the study indicated that irrigating at the less stressful 0.4 and 0.6 centibars significantly increased crop growth rate and days to 50% tasseling and silking. This may be due to abundant moisture supply which enabled the crop to respond to this growth resource favourably which resulted in good growth. This supported the observation reported by Ibrahim and Kandil (2007). The significant response to irrigation during the vegetative phase of growth may due to the fact that the roots were still developing, and hence had not reached deeper to tap moisture in the lower soil layers and this meant that varying irrigation could affect the crop performance.

Increasing plant population from 33,333 to 44,444 and 55,555 plants $ha^{-1}$ produced similar NAR at 8 weeks after sowing in the first two years, but significantly decreased the net assimilation rate per plant at 66,666 plants $ha^{-1}$. Similarly, during the first two years, at 12 WAS, 44,444 plants $ha^{-1}$ had significantly lower NAR than the other treatments. In 2009, increasing plant population from 33,333 to 66,666 plants $ha^{-1}$ resulted in significantly lower NAR at both sampling periods. This may be due to the influence of leaf area per plant. The lower plant population may have had larger leaf surfaces resulting in higher leaf area per plant and thus higher net assimilation rates than the higher population treatments. It may also be due to proportionally less increase in dry matter accumulation per unit area as compared to increase in LAI. This results are in line with the findings of Ahmad alias (2010), Ma et al. (2007), Maddonni et al. (2001), Mohsan (1999) and Naeem (1998) who stated that increasing plant population decreased net assimilation rate. Leaf area index, LAI, was also significantly affected by variation in plant population. The results of this study indicated that increasing plant population resulted in significantly higher LAI at 33,333, 44,444 and 55,555 plants $ha^{-1}$ which had similar LAI but were significantly higher than 66,000 plants/ha respectively. Many workers have reported an increase in LAI as plant population is increased (Sulewaska, 1990; Dwyer et al., 1991; Eseche, 1992; Hamidu, 1999; Ahmad alias et al., 2010; Amanullah et al., 2010). This may be due to the fact that since the estimation of LAI is based on LAI/plant, the aggregate sum of the various plants will translate into higher LAI for the more numerous plant populations. The higher the population, the more leaves produced and the greater the leaf area index (LAI). Nunez and Kamprath (1969) and Hunter et al. (1975) found that the total LAI increased linearly with increases in population from 34,000 to 69,000 plants $ha^{-1}$, after which the LAI would start to decrease. Similarly Luque et al. (2006) and Liu et al. (2004), reported that increase in plant population tends to decrease LAI per plant but increase LAI per unit area. Increase in plant population may cause significant reduction in leaf area per plant due to small leaf size. However, ground area per plant is decreased more steeply with increasing number of plants per unit area thus leading to an increase in LAI. Furthermore, increase in light interception at high than at low plant population may lead to higher LAI.

## Conclusion

The results of this study showed a significant response to variations in plant population by many of the parameters. Increase in plant population significantly increased net assimilation rate and days to 50% tasselling, amongst the growth factors. Based on the results obtained, it can be concluded that the use of genotype EV-DT W99 STR QPM, 60 centibars irrigation schedule and 55,555 plants $ha^{-1}$ had resulted in good agrophysiological characters of quality protein maize at Kadawa. Further studies may be necessary to determine the appropriate fertilizer rate which may increase the yield under irrigated conditions.

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# Bio fuel production and its implication on food security: Case study from Zambia

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**The objective of this paper is to present a comprehensive review of the status quo of bio-fuels developments and the policy regimes including support measures driving the social, environmental and economic impacts of bio-fuels development. As it has been promoted by national policies markers, there is still no common consciences on its implication in achieving food security. The case study was based on a Meta evaluation carried out in Zambia; the key findings indicated that there is possible diversion of labour, land, extension service to bio-fuel and competition of input use might lead to reduction of food production and high food prices if the biofuel market proves lucrative. However the price of bio-fuel feedstock from Jatropha in Zambia was not attractive enough to encourage farmers to grow more Jatropha and this has raised major concerns by both farmers and policy makers.**

**Key words:** Zambia, meta evaluation, Jatropha and policy implications.

## INTRODUCTION

For Africa, access to secure, sustainable and affordable energy is pathway and critical for sustainable development; as it has an ability to vital services in improving quality of life that is essential inputs for socio-economic development at regional, national and sub-national levels (Singh and Sooch, 2004). In addition to this, it can facilitate education and communication; further enhance health care services and good strategy in responding to climate change.

The biggest challenge in Africa, firstly the inability in providing adequate energy services has been a major constraint in achieving sustainable development. Secondly, imported oil imposed heavy economic burden and reduces energy security in Africa. Therefore, renewable energy technologies (RETs) specifically bio-fuel is vital in offering prospect of self-reliant energy supplies at national and local levels, with potential benefit to economic, ecological, social, and food security benefits (Biswas et al., 2001). This implies that there is urgent need for substantial investment in domestic energy infrastructure for social improvement and economic growth. In addition to this, RETs can facilitate trade in energy by strengthening regional and intercontinental infrastructure such as electricity transmission lines, oil and gas pipelines within Africa and other continent (e.g., within Europe). Expanding national and regional infrastructure would also increase the efficiency of how Africa uses its energy resources, thus enabling Africa to increase its reliability of supply and reduce its dependence to oil imports (Amigun et al., 2008). This would improve energy security and increase access to energy services.

Bio-fuels development, particularly in the context of African development, is a controversial issue that has recently attracted considerable interest among policymakers, development practitioners, donors and other stakeholders. Bio-fuels can lead to a substantial reduction in greenhouse gases emissions. These reductions require careful measures in crop selection management, subsequent processing and transport of bio-fuels to the point of use, as the case of Zambia.

The principal source of energy in Zambia is wood fuel

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(that is, firewood and charcoal), with the largest consumer group being households in both rural and urban areas. About 95% of the electricity supply comes from hydropower, while 97% of the rural people do not have electricity (World Bio-energy Association, 2010).

The transport sector is fossil fuel-dependent, that is, 60 to 65% of the imported fossil fuel is diesel - about 3 million L/day bio-energy initiatives are mostly on liquid form; biofuels is principally Jatropha. Government promotes energy-efficient usage of bio-fuel; to encourage bio-fuel there is no sales tax or excise on bio-fuels in Zambia (World Bio-energy Association, 2010).

Zambia has very good arable land for both extensive and intensive cultivation of various crops. Some 22% (16.5 million ha) of Zambia's total land area is available for agricultural production and only about one seventh of the total arable land is under cultivation, mostly by small-scale farmers. Water is in abundance (World Bio-energy Association, 2010).

Zambia have 43.6 million hectares of arable land, of which only 14% or 6.1 million hectares were currently being cultivated. The Jatropha plant has existed in Zambia for several decades. The plant has often been used as a hedge around gardens in order to protect the crops from animals. However in the last few years many activities have been undertaken to introduce Jatropha as a new crop to the small-scale farmers to improve income and to reduce the dependence on imported fossil fuels. Zambia imports annually around 700,000 tonnes of fossil fuels and about 10% of the GDP is used to pay for this import (World Bio-energy Association, 2010).

## LITERATURE REVIEW

### Africa bio-fuel development

As indicated in Amigun et al. (2011), to date, only a few African countries have implemented effective support policies for renewable (biofuels) energy (those countries are Ghana, Angola, Mozambique, Nigeria, South Africa, Tanzania, Zambia, Zimbabwe, Uganda, Benin, Mali, Malawi, Senegal, Mauritius and Swaziland).

The supply and use of renewable energy have never been static subjects. Scientifically, technologies change; some are entirely new and others result in improved function and efficiency. Structurally, supply organizations vary, ranging from nationalised utilities to privately owned companies. As a result, during policy dialog different countries engage different stakeholders. For example, in Nigeria and Uganda the government facilitates development, provides stimulus for private sector investment, and monitors and coordinates the energy sector activities. Thus, the government and public universities plays significant role players in the energy sector (Jumbe et al., 2009). In contrast, South Africa, Tanzania, Zambia and Malawi where the private sector, foreign companies and non-governmental organizations are responsible for biofuels strategy and policy recommendation and formulation (Amigun et al., 2011).

South Africa and Ghana have developed specific biofuel strategies with specific targets. The South African industrial biofuel strategy aims to achieve a penetration level of 2% of biofuels (400 million litres per annum) in the national energy supply by 2013 (Thomas and Kwong, 2009). The crops targeted for the production of biofuels include canola, soybeans and sunflower for biodiesel and, sugar beet and sugarcane for bio ethanol (Thomas and Kwong, 2009). The Government of Ghana has set a target of substituting 20% of the national gas and oil consumption with biodiesel by 2015, and 30% of the national kerosene consumption with Jatropha oil by 2015. The policy also aims at improving the efficiency of biodiesel production in order to reduce production costs. In the case of Mozambique, the national energy policy is not yet finalised but the country has already adopted preliminary regulations to foster the large-scale production of biofuels. The policy proposes the gradual introduction of blending of petrol (gasoline) with ethanol and biodiesel with fossil diesel, initially, at 5 to 10% (Thomas and Kwong, 2009).

As indicated in Amigun et al. (2011), South African synthetic fuels company, Sasol, which pioneered the use of petrol and diesel from coal and natural gas in a joint effort with the government's Central Energy Fund, was able to build a biodiesel production plant based on soya beans. The benefits of the government's plans are:

(i) Diversification in agriculture;
(ii) Utilizing and transforming the countries expertise in producing oil from coal;
(iii) 55,000 new jobs, mostly rural;
(iv) Reduction in national unemployment by 1.3%;
(v) Increase in GNP by 0.12% (6% of the rural fraction of GNP);
(vi) Reduction of imported oil, improving balance of payments by nearly 0.5 billion USD per year;
(vii) Meeting 75% of the national renewable energy target of 10,000 GWh/year by 2013; and
(viii) Reducing fossil-carbon emissions

The question is that, is there enough land for food and bio-energy in Sub-Saharan Africa?, today, less than 9% of the total land area of 3 billion hectare is currently used for crop production: 45% of the land being water bodies, desert, barren, steeply sloped, or very marginally productive, 18% being forest and 6% otherwise protected land, and less than 1% urban and built-up areas in Africa. Pastures, savanna and bush cover 22% of the land, with a wide range of bio-productivity. It is estimated that about half of the annual biomass produced in these areas is currently needed to support ruminant livestock (Figure 1) (Rajagopal and Zilberman, 2007).

Though it serves as a key point to enhance food

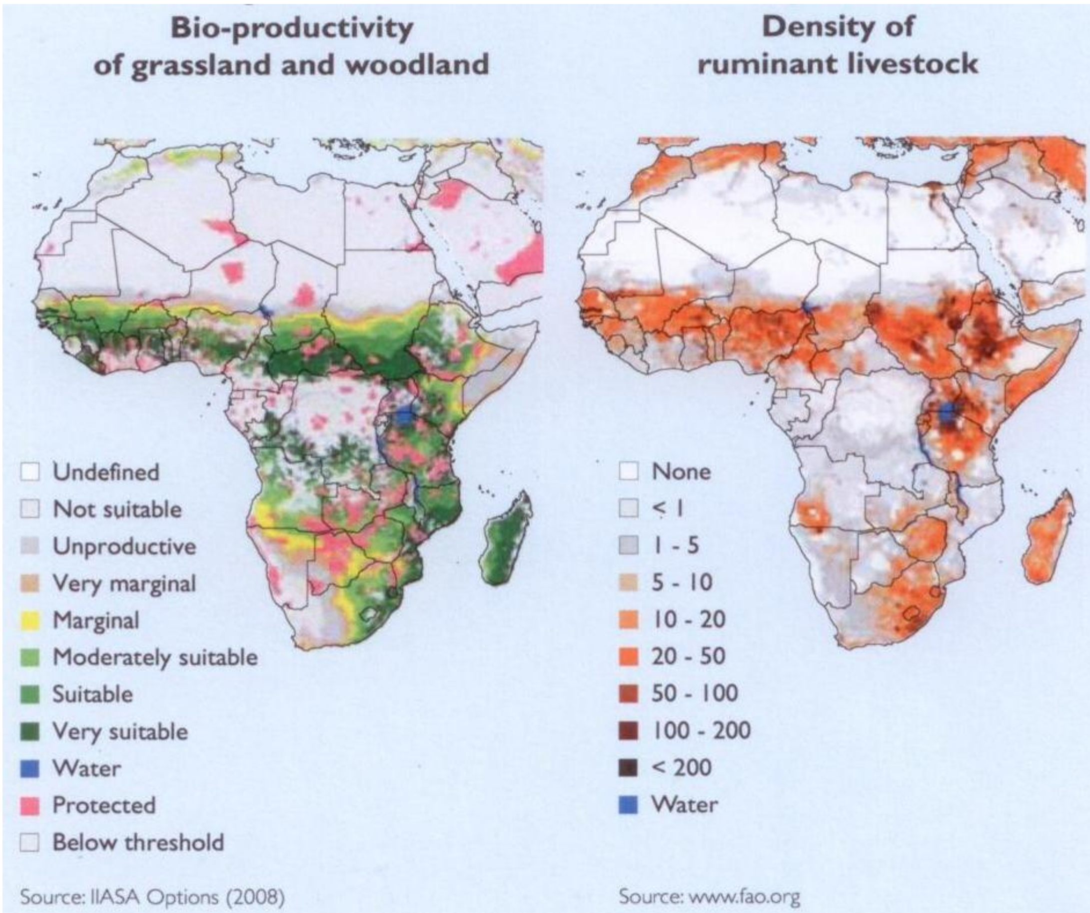


**Figure 1.** Bio-productivity of grassland, woodland and density of ruminant livestock. Source: OFID (2009).

security by achieving sustainable yield improvement on current cultivated land, simultaneously it is possible that up to one-third of savanna and bush, that is, 175 to 200 million hectares, could be used for food and energy production. While conventional agricultural feed stocks currently used in first-generation biofuels production compete with food crops and perform poorly for environmental criteria (OFID, 2009).

Second-generation technologies promise substantial greenhouse gas savings and may permit tapping into land resources currently not or only marginally used.

The diversion of arable land from food production to bio-energy production has been anticipated to likely result in food production and food security conflict. Biofuel proponents, and there is already a vocal ‘biofuel lobby’ argue that bio-energy crops would only be grown on degraded or wasteland, not fertile land.

But, if the wasteland is capable of supporting Jatropha cultivation, should it not be used for the cultivation of selected cereal or oil crops, or if not that, then fodder grasses? India and all of South Asia have large livestock populations, which serve as additional support for local food security. The region is deficient in fodder and all kinds of non-arable land should be diverted to fodder grasses, not crops to produce agro-fuels (IFPRI (International Food Policy Research Institute, 2008).

Critics fear that the growth of the agro-fuel sector will be detrimental to food production. The impact on food prices of diverting food crops to ethanol production is already becoming visible. Pork prices in China have begun to rise as a result of rising costs of animal feed consisting principally of corn and soybean, both crops that the US is diverting to its biofuel programmes. Less US corn and soybean on the market mean higher prices for animal feed and so higher prices for meat. Beijing is slowing down China’s ethanol production drive after increase in corn prices worldwide prompted concern about inflation and food security at home. China is the world’s number-three ethanol producer, after the US and Brazil, manufacturing 1.2 million tonnes of ethanol from corn and wheat feedstock. Chinese officials are waking up to the fact that they will not be able to produce enough corn to supply domestic food needs and support a biofuel programme. These officials realize that they cannot buy enough corn from the world market either, with the US, the world’s largest corn supplier, hoarding its corn and soybean for its own ethanol programme (IFPRI, 2008).

Warning signals about the consequences of the US led biofuel fad on food and feed availability are being sent by the FAO. A report prepared by the World Food Organization and the OECD predicts that the current trend will take land out of food production and increase the price of commodities such as sugar, maize and palm oils (OFID, 2009).

The report anticipates that this will lead to a rise in food prices over the next ten years. While higher food prices will be profitable for food exporting countries and large farmers, they will threaten the economies of food importing countries, the livelihoods of their farmers as well as the food available to the urban poor in these countries (OFID, 2009).

The global rush to switch from oil to energy derived from plants is being led by the rich countries who want to see energy plants grown extensively for fuel as a way to reduce their own climate changing emissions. The UN is urging governments to beware of the human and environmental consequences of the agro-fuel trend, some of which could be irreversible. They warn that taking the current agro-fuel route will lead to deforestation, push small farmers off the land, and lead to serious food shortages and increased poverty. India should review its biofuel policy and examine the natural advantages to see what kinds of strategies are viable for producing supplementary energy (OFID, 2009).

## METHODOLOGICAL FRAMEWORK

In this study, a mega evaluation was carried out for the case of Zambia to indicate possible diversion that might result in energy applications and benefit that might be driven taking few farmers as case study.

The term ‘meta-evaluation’ was coined more than 40 years ago by Michael Scriven (1969). In simple terms, meta-evaluation means the ‘evaluation of evaluations’ (Gough and Martin, 2012). Meta-evaluations are concerned with bringing together the evidence from a range of studies and exploring implications for policy and practice and so overlap in purpose and methods with broad-based systematic mixed-methods reviews ('synthesis studies') and methods for testing the evidence for policy programmes (Gough and Martin, 2012).

The starting point for this study is that of meta-evaluation and combination of evaluation science and methods of research synthesis. It involves consideration of the methods for identifying relevant primary research studies, methods that assess quality, relevance and techniques that are able to bring interpretation of empirical data collected and field visit observations; the approaches include open discussion and communication with the audiences for meta-evaluation of the target group. The methodology has included:

**International literature review:** A detailed review of the existing academic literature on energy that were carried out before in order to clarify processes of meta-evaluation.

**Roundtable discussion on methods:** Discussions that are mainly the main analysis of the evaluation in this study which was convened between the farmers experience on “Jatropha” in Zambia to enable them examine the strengths and weaknesses of their farming with bio-fuel. The outcomes of these discussions also inform the industry and policy makers.

**Consultation with the energy industry:** Primarily, the research was designed with a special request that industries engage farmers to increase production, and to further document public and private perceptions toward bio-fuel. Therefore, in this study there was experts opinion included in the study; those directly involved on bio-fuel in Zambia to assess in more detail the strengths and weaknesses of their experience and the practical lessons learnt, and to collate examples of useful lessons that enable or assist policy frameworks.

**Analysis and reporting:** Using the findings from the literature review, roundtable discussions and primary research, a set of recommendations and guidelines on the stages and steps involved in conducting meta-evaluation were developed.

## RESULTS AND DISCUSSION

### Bio-fuels landscape in Zambia

Since time immemorial Zambia has been a net importer of petroleum requirement that represents 9% of the total national energy demand. It is used mainly in the transport sector and a small percentage dedicated for thermal power plants in remote areas that are not linked to the national grid. The mining and agricultural industries are the major consumers of liquid fuels (Republic of Zambia, 2008).

The petroleum is supplied via a 1700 km pipeline from Dar es Salaam in Tanzania to Ndola, on the Copperbelt, where the only refinery of Zambia with a total of 1.1 million metric tons/annum is located. It is from this facility that LPG, HFO, Petrol and Diesel is produced and distributed throughout the entire country by Oil Marketing Companies (OMC) (Republic of Zambia Ministry of Energy and Water Development (MEWD), 2008).

In terms of consumption, the transport sector takes about 53% while the mining sector consumes 27% of the total production. Of this there is no contribution by bio-fuels as this sector is in its infancy except of some very few self consumption projects. The Figure 2 shows the consumption of petroleum per sector (MEWD, 2011).

### Biofuels development in Zambia

The Zambian government is aware that to have a sustained economy growth that currently oscillates at 6% GDP growth per annum, it is important for the country to have a sustainable energy supply that includes a very vibrant liquid fuels sector. While the main driver for biofuels development in the developed world is to curb green house gas emissions responsible for global warming and climate change, the main driver in most developing countries in sub-Saharan Africa is energy security, employment creation and rural development (MEWD, 2011).

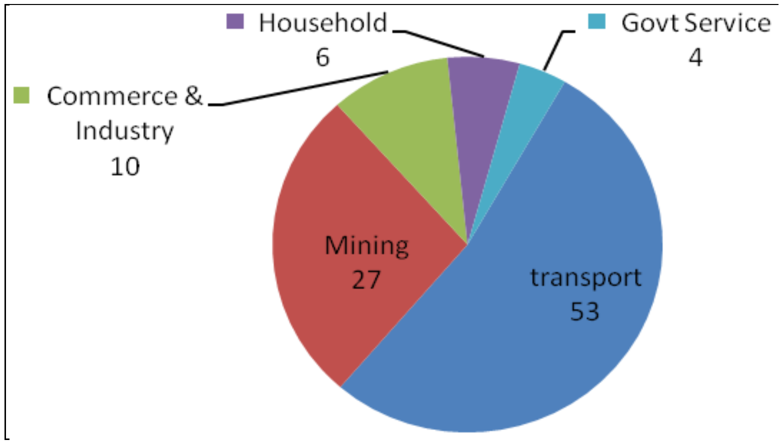


**Figure 2.** Consumption of petroleum fuels in Zambia. Source: MEWD (2008).

With the recent sharp fluctuations in the crude oil prices and the increasing instability in the oil producing countries, the Zambian government has identified the importance and significance of biofuels potential to contribute to the energy security in the country. This is evidenced by the development of a Bio-fuels Industry Strategy and the inclusion of biofuels sector in the National Energy Policy of 2008. The recent pronouncements of voluntary blends by the Minister of Energy and Water Development, is a major indication that the government is ready to develop this young but important industry in Zambia (MEWD, 2011).

## Status of bio-fuels development in Zambia

The National Energy Policy identifies bio-fuels as part of the national energy mix that currently is dominated by the use of biomass in terms wood fuel. Wood fuel is responsible for some 70% of total energy consumed in the country especially in rural areas and urban poor communities. Although Zambia is endowed with a very rich landscape covered by woodlands and forests, with the growing rate equivalent to 4.3 million tons of wood, dependence on this energy source pose a major threat to national forests as consumption has over stripped regeneration rates of the indigenous forests (MEWD, 2008).Finding alternative sustainable energy supply accessible to the rural remote areas is one of the drivers of developing the biofuels sector.

## Institutional framework

The development of the biofuels sector at the moment is driven by the Ministry of Energy and Water Development (MEWD) and the private sector through the Biofuels Association of Zambia (BAZ). The National Energy Policy provides the general guidelines for the development of the biofuels sector while the National Biofuels Industry Strategy Paper adopted by the MEWD in 2008 provides the specifics of how the country wants to develop the sector. In terms of legal framework and the absence of the biofuels act and regulations, the sector is regulated by the petroleum, petroleum production and exploration and the energy regulation Acts while the Environmental Protection and Pollution control Act performs a watch dog mechanism to ensure the development of the industry is environmentally sound (MEWD, 2008). The Statutory Instrument No. 42 of 2008 provides the basis for inclusion of biofuels on the Energy Regulation Act. It gives power to the Energy Regulation Board as the agency to regulate production and utilization of biofuels. In terms of standards, Zambia Bureau of Standard has included the ZS E 100 and ZS B100 standards for ethanol and biodiesel respectively.

Although the development of the biofuels industry in Zambia is squarely driven by the MEWD, it needs to interact with other legislation pertaining to land, agriculture, labour, commerce and industry and other human rights (MEWD, 2011). German and Schoneveld (2012) explore the extent to which Zambia positioned to leverage future benefits of the emerging industry while forestalling negative social and environmental costs. The key findings suggest that while existing and incipient policies and legislation provide an important foundation for attracting investors and achieving diverse sector aims, a number of gaps remain that are likely to hinder efforts to leverage meaningful benefits while minimizing negative impacts. On the other hand, Duvenage et al. (2012) noted implementation of bio-fuel in Zambia is unevenly distributed in terms of costs and benefits, as a result there is gap in knowledge, access to resources and the allocation of social and political influence; this compromises the sustainability in biofuel in Zamibia.

## Choice of feedstock

The draft Biofuels Industry Development strategy paper identifies six major sources of feedstock for biofuels production. For ethanol, molasses coming from Sugar factories, cassava and sweet sorghum are the feedstock preferences in Zambia. Maize although produced in surplus is not to be considered as it is the stable food of the country and diversion of maize to biofuels can cause an imbalance in terms of food security and trade (MEWD, 2011).

As for biodiesel, palm oil, Soy Beans and Jatropha have been identified as the potential crops to provide the feedstock. Sunflower, being a food crop, must be approached with caution to avoid competition with animal feed production and vegetable oil for human consumption (MEWD, 2011).

Since the entire primary production is agro-based, the National Agricultural Development Policy plays a significant role in the development of this agro-based bio-fuels industry (MEWD, 2011).

The strategic paper promotes the concept of starting small and then rolling out the programmes as the country builds its knowledge base, infrastructure and experience necessary to upscale bio-fuels production (MEWD, 2011).

## Land, food security and bio-fuels

It is a very well known fact that the greatest natural resource that Zambia has is land and its natural resources (especially mineral deposits). The Government has recognized the importance of this resource in the development of a strong and prosperous nation (MEWD, 2011).

Zambia is endowed with a good agro-climatic condition with abundant arable land and over 50% of total water resources of the SADC region. At present the country uses only 14% of the total arable land of approximately 42 million ha (DFID, 2001). The water resources that provides a huge potential for irrigation is currently under developed with only some 65,000 ha under irrigation which is less than 15% of total potential.

Although Zambia produce surplus maize (about 2 million metric tons during 2010/2011 farming season), majority of this production is by small-scale (commonly referred to as peasant) farmers. This is a very labour intensive practice and therefore contributes about 60% of the total labour force in the country. However the agricultural sector is extremely inefficient leading to low productivity per hectare. Although there is plenty of land, the sensitiveness of the agriculture sector demands policy coordination between the energy and agriculture sectors.

In terms of land administration, land in Zambia is vested in the president. It is divided into two major categories: statutory land and customary land. Under statutory, land rights can be registered in form of a lease of maximum period of 99 years. This is the highest form of tenure security possible. On the other hand traditional land, which covers most of the so called trust lands, can be perpetually held under customary law. There is a possibility to convert land from customary to statutory but not vice versa, a condition that has raised a lot of resistance especially by the chiefs. The Lands Act (1995) makes provision for such but the procedure is not as simple in practice as it is on paper (Chileshe, 2005).

Under the current system of tenure, Customary Land[1] constitutes about ninety percent (90%) of the total land area of Zambia, which is seven hundred and fifty-two thousand (752,000) square kilometres while State Land constitutes only 10 percent (10%) of the total land area (Chileshe, 2005).

A lot of land that is being targeted for bio-fuels development is therefore not surprisingly mainly customary which is not formally recognized by the financial system. Development of a vibrant bio-fuels industry will require a favourable land access system that benefits the local people but at the same time encourages the much needed investment without leading to “land grabbing” (Chileshe, 2005).

## Market potential for biofuels

The announced blending ratios and the biofuels regulations and standards (Ministerial speech, MEWD, 2010) has unlocked the biofuels market in Zambia. With about 1.0 million metric tons of diesel consumption, the 5% blend provides some 250,000 metric tons assuming blending is mandatory. With the increase in mining and agricultural activities which subsequently pushes demand for transportation and energy, the market for biofuels promises an upward trend.

Despite the announcement of the blending ratios that was a major bottleneck in the development of biofuels, there is no project that is producing biofuels on a commercial basis. We may see an increase in investment now but alignment of other sectors would be crucial to the development a sustainable market and infrastructure. There is still a lack of blending infrastructure at the only refinery and national storage facility in Ndola.

## Field visit to assess bio-fuel in Zambia

The visit to Kisalala area at Mbambiko village, a zone led by Mr. Gladson Kyupa has 65 contract farmers under Bio-ex project, of which 12 are women. Of the 13 farmers interviewed, one farmer indicated that to have land size of 24 ha. Table 1 summarized the land ownership and the number of Jatropha planted. The farmers indicated that

[1] Customary land was before independence composed of reserves and trust lands established by the colonial master.

**Table 1.** Size of Jatropha plantation in Zambia.

| Land size (ha) | No. of farmers | Jatropha planted |
|---|---|---|
| Less than 10 | 6 | 500 (that is, 1 ha at 5×5) |
| 10 – 20 | 6 | 500 (that is, 1 ha at 5×5) |
| Over 20 | 1 | 1600 (that is, 3 ha at 5×5) |

**Table 2.** Price of different crops in Zambia**.**

| Crop | Price in USD / kg |
|---|---|
| Beans | 1.25 |
| Cassava | 0.42 |
| Groundnuts | 1.04 |
| Jatropha | 0.14 |
| Maize | 0.23 |
| Millet | 0.42 |
| Sorghum | 0.42 |
| Sweet Potatoes | 0.35 |

they had knowledge about Jatropha as an ornamental plant but not its use and economical value as they know it today.

In terms of income from other crops, the interviewed farmers indicated that millet gives the most income as it is processed into a local beer that sells better and for a longer time of the year, depending on the amount harvested. Of the interviewed farmers each farmer earned an average K3.5 million per annum (equivalent to USD 700/year) from different farming activities.

When asked whether they have benefited economically from the project, most farmers indicated that it was too early to indicate this but were disappointed by the perceived low price of Jatropha offered by NWPB. At the same time, several of the 13 farmers indicated the willingness to expand their Jatropha cultivation and some have set up nurseries in readiness for the next season.

The main complaint that was heard was the labour demand of Jatropha. Farmers indicated that they had to divert labour to tend to the Jatropha plants especially for weeding and pruning. Those that have harvested indicated the tedious and laborious picking and shelling process. This in their opinion, poses a potential labour competition with other crops especially if they expand their Jatropha fields.

In terms of training, farmers in this area expressed their disappointment that despite the promise that training would be given, they only received seeds and/or seedlings and not the promised training and field extension services. However, during meetings, tips on how to look after the plants like pruning and weeding were given. Basic knowledge about use of agriculture waste coming from Jatropha and other crops as composite fertilizer was conspicuously absent.

### Market development in bio-ex

North West Bio Power (NWBP) and SNV were responsible for the organization and development of the mechanism to support Jatropha market development. The contract signed between NWBP and the farmers was aimed at guaranteeing a market for the Jatropha seeds at the agreed price of 8% of ruling diesel price. At the time of the visit, this worked out to be less than K500/kg although NWBP was buying at a high price of between K650 and K1000 per kg.

As indicated earlier, over 8000 out-growers were recruited but only a few of the interviewed farmers indicated to have sold their first yields. The out-growers spoken to indicated that the price being offered for a kg of Jatropha seeds is below their expectation. This expectation could not be established well but was based on a mere comparison of Jatropha seed price to maize. Some even kept some seeds in anticipation of a higher offer later on. However, when compared to the other crops' producer prices as shown in the Table 2, Jatropha price per kg did not compete well in terms of gross income. This price discussion, however, needs more analysis and information sharing for the farmers to understand the pricing structure of the Jatropha seed. The table indicates the producer prices of various crops as obtained from PACO in comparison with Jatropha. At national level, the announcement of biofuels blend percentages has created the much needed market for biofuels due to sudden demand created to meet these targets. Market development requires that all stakeholders ranging from government, private sector, development partners, the farmers and regulators work together. The strategy that was adopted in Bio-ex could have been more effective if there was deliberate engagement of stakeholders to address issues related to pricing and logistics in particular. Working closely with BAZ, Energy Regulation Board and MACO would have improved these aspects. Such alliance would have assisted in pushing government to implementing some of the incentives as proposed in the Ministry of Energy and Water Development's Biofuels' Industry Strategy adopted by the cabinet in 2008. Perhaps this will happen in the near future as compulsory blending targets are being discussed at the moment and may change the entire biofuels and agricultural landscape.

## Food production and security in bio-ex areas

The issue of food production and security is a very sensitive one especially in countries like Zambia where the targeted out-growers are responsible for over 75% of total food production in the country. Bio-ex was designed to supplement income of the subsistence farmers by introducing a cash crop in their farming system. In a project of this nature, there are a number of possible diversions that can lead to reduction in food production in the communities. These include:

**(i) Diversion of land meant for food production to Jatropha, leading to reduction in the amount of land available to grow food:** In Bio-ex, the issue of land diversion is extremely minimal as most farmers interviewed had more land than they could possibly use. They utilized under at least 50% of what they had in total. It means that Jatropha growing can be done on excess land that each farmer has. However this needs to be managed and monitored very closely and hence the need for good extension services. In this sense Bio-ex did not cause reduction in land meant for food production.

**(ii) Diversion of labour and other production tools to Jatropha, thereby creating labour conflicts with food production:** In Bio-ex, this seemed to have been a major concern by the farmers. They expressed the tediousness and laborious aspects demanded by Jatropha from the time it is planted until harvesting. It seems to be competing with maize harvesting for example during fire-breaks creation and weeding. Harvesting, especially husking, seems to compete with other domestic and farming chores like food processing and harvesting sweet potatoes, beans and millet. This therefore could have led to the losses that the communities visited expressed. However, this needs to be analyzed further to avoid making uninformed conclusions.

**(iii) Diversion and/or dilution of investment to Jatropha:** This means savings earned from other activities can be diverted to Jatropha for land preparation or input procurement as an example. This was evidenced in the amount of money spent on labour hire for weeding and husking. Bio-ex did not make any provision for appropriate manual husking tools that could have reduced labour input. This diversion has had a negative net effect in some cases when the average income of interviewed growers reduced by at least 40% due to diversion of income.

**(iv) Diversion of agriculture extension services from food to Jatropha:** Jatropha is a new crop that needs to be understood further if it is to deliver benefits to the growers. It provides an opportunity to diversify land utilization and intensified agriculture extension. However, it can be said that in Bio-ex, dedicated extension was required since the crop expansion was something new to the community. Little local knowledge was available on Jatropha and this meant that more close supervision was needed. The MACO extension services side was not forthcoming. If that happened, perhaps there was going to be a loss of extension services meant for food production. This was not evidenced since MACO did not divert their extension services to Bio-ex.

**(v) Diversion of markets when price of Jatropha is way above that of food crops:** In a situation where Jatropha or any energy crops become lucrative, farmers may decide to divert land, investments and whatever they possibly can to earn that extra income. This can cause serious food production reduction and maybe food price hikes. In Bio-ex, this was not the case as Jatropha price being offered was perceived by farmers to be lower than that of maize and other crops.

**(vi) Fertiliser inputs to Jatropha:** This might result in competition with crop production that can create price spike in future.

**(vii) Attraction of foreign investment:** For example, China is negotiating for five million acres in Zambia to grow Jatropho (Amigun et al., 2011). The large scale mechanised production of energy crops becomes a big concern in most African nations, as there is tendency of land grape by richer nations.

**(viii) Impact on food prices:** Amigun et al. (2011) shows in their study that increased demand for biofuels is responsible for about 30% of the weighed grain price increase from 2000 to 2007. Many Africans spend over 50% of their share of income on food and many African countries import food to meet their domestic energy demands. In the year 2000, the average total imported cereal demand in sub-Saharan Africa was 33%, with Sudan, Gambia and Zambia reaching a high dependency level of more than 80%.

**ix) Multiplier effect on income:** Biofuels development is argued to have positive benefits in ensuring household food security through increased incomes and the growing export markets for energy crops. There are however, number of factors that are not explicitly accounted for in many of the partial-equilibrium frameworks that generate these conclusions. In some countries in Africa, concerns surrounding food security have resulted in governments actively cautioning the development of biofuels. In Tanzania for instance, as a result of mounting pressure from farmers and environmental groups, the government suspended all biofuel investments and halted land for biofuel development. In South Africa, maize was excluded from ethanol production amid food security concerns in the draft biofuel strategy. Biofuel developments also present a potential competition between biomass systems for biofuels production and the use of resources for animal feed, bedding, fertiliser and construction materials. Of particular concern are threats from business orientated production of biofuels that may require opening of forests or acquisition of land from rural dwellers for growing energy crops. Additionally, the market prices of energy crops may be greater than for food and induce the diversion of resources away from food to biofuel production; thereby threatening food security (Amigun et al., 2011). However, all this implication was not proven in the case of Zambia as the case study focus was only targeting the poor resource farmers.

Bio-ex project made an attempt to demonstrate how development of a biofuels industry can bring benefits to small farmers in Zambia. The following is an attempt to sum up visible achievements of Bio-ex Project in North Western province as observed during the evaluation of the field visit:

(i) The Bio-ex was designed to reach out to 3500 farmers at the end of implementation period. It was very overwhelming to notice that over 8000 farmers were reached. The exact figure was difficult to establish since the database which was to host all such information was not inspected but independent partners and field officers confirmed the figure of over 8000 farmers of which over 2000 were female out-growers. These farmers are divided into some 72 zones with under 10% female zone leaders. In order to increase access to benefits by women and other vulnerable groups, a project of such nature would need close collaboration with other projects and NGO or Civil societies working in the gender sector. Leaving such a task to a private sector in a fairly complex and ‘new’ industry would not be appropriate. The Biofuels Civil Society supported by Oxfam would have provided this watchdog role in the project to make sure farmers and investors achieve a win-win situation.

(ii) Great awareness and expectations on Jatropha in the province has been created. Many even non-Bio-ex farmers and other no-project actors confirmed knowledge about Jatropha when asked. However the level of information possessed by different stakeholders varied greatly. Those involved in the project demonstrated a better knowledge than those who did not participate. One farmer interviewed independently indicated that he heard about this Jatropha project on radio and decided to join the project. This awareness needs to be sustained in order not to lose the momentum created in the province.

(iii) The Bio-ex farmers benefited in terms of knowledge about Jatropha and its potential, gained experience of how to organize themselves in a farming zone or group, and general farm husbandry practices shared in meetings. The introduction of intercropping strategy with annual crops such as sunflower and other low crops like sweet potatoes, beans and groundnuts, may be an added benefit to the farmers as they can utilize the same piece of land for different things and save farm management labour and time as weeding one crop means the other ones are weeded too. However, the farmers needed more knowledge to increase the chances of reaping the benefits from Jatropha.

(iv) At national level, the Bio-ex project enhanced the visibility of other Jatropha growers as there were a number of radio and TV adverts and some discussion programmes that included the announcement of markets.

(v) Field officers gained more knowledge and practical experience about Jatropha and its production complexities. However they needed more indepth training on the agronomical to provide good extension services to improve effectiveness of their extension services.

(vi) The project also provided a platform to engage key stakeholders needed to develop a sustainable biofuels industry. After the Bio-ex project, MACO has a positive view now, and plans to include Jatropha growing in its expanded agriculture diversification programmes. MACO as a government ministry needs to develop a deliberate programme targeted at Jatropha farming in order to support the sector effectively but also avoid compromise in food production.

(vii) Involvement of BAZ in the project provided the link needed to establish develop networks that can enhance the young industry. However, the lose arrangements and the failure to integrate research institutions in the project caused an opportunity loss to carry various investigations needed to develop best practices. Institutions like UNZA’s Agricultural School, CBU’s Forestry School, CSIR and Mt. Makulu Research Institute and GART for example would have provided the needed expertise to improve the plant and its value chain in the Bio-ex. Also this would have been an opportunity to test various Biofuels sustainability principles and standards being proposed by RSB and other agencies.

(viii) Experience regarding how a private company can work with a development organization was a valuable lesson for both parties. Bio-ex project design from inception desired to see how this partnership can be achieved. Despite many hitches as recorded during the evaluation, the Bio-ex project demonstrated that it is possible but requires a different approach to classical government or NGO approach. Therefore it would be necessary to evaluate in detail this alliance and explore possibilities that can make this work better.

(ix) Another significant spin-off from the project is the formation of the North-western Out-growers Association (NOWEGA) in December 2009 aimed at providing one voice (hopefully stronger) for the growers. NOWEGA is determined to explore the possibility of (re)negotiating the contracts signed by the out-growers with NWBP and take over the mobilisation of the growers as a means of increasing efficiency. It also plans taking over distribution of inputs, collection of seeds from growers and negotiation of future farming contracts for the growers. NOWEGA then would in turn sell the seeds to NWBP or any other company without compromising on the current contractual obligations to NWBP. SNV has indicated its willingness to support NOWEGA as this would complement their effort of developing the capacity of communities to engage in agricultural business effectively. NOWEGA expresses also the desire to explore possibility of procuring appropriate oil extraction technologies to localise benefits from Jatropha such as seed cake and husks re-use as organic fertilizers. This also may increase the profit margin since only the oil needs to be transported compared to seed which is very bulky. The knowledge of extraction would also remain in the community. Therefore NOWEGA as an initiative has potential to provide the missing link in Bio-ex implementation.

## Conclusions

Food and energy security as well as climate change mitigation are all critical to social, economic and environmental sustainability, not only at the national level but also globally. A successful resolution of these challenging issues requires the goodwill and commitment of all nations to work together.

Biofuel development polices have a direct impact on these triple challenges and yet it is national polices with national interests that have been the driving force of setting biofuel targets. The global and spatial agro-ecological and socio-economic methodology and assessments required to provide the analytical means and science-based knowledge to evaluate policy options towards making the right choices that recognise the pitfalls and mobilise the opportunities to make progress towards achieving national and global sustainable development.

Bio-fuel in Zambia created diversion of land meant for food production to Jatropha, leading to reduction in the amount of land available to grow food. However, In Bio-ex, the issue of land diversion is extremely minimal as most farmers interviewed had more land than they could possibly use. However this needs to be managed and monitored very closely and hence the need for good extension services. In this sense Bio-ex did not cause reduction in land meant for food production.

Diversion of labour and other production tools to Jatropha thereby creates labour conflicts with food production. In Bio-ex, this seemed to have been a major concern by the farmers. They expressed the tediousness and laborious aspects demanded by Jatropha from the time it is planted until harvesting.

In future, bio-fuel might create competition in the input use, especially in fertilizer input, that might lead to high production cost. Furthermore, feedlot industry might collapse; and maize major feed lot major input might be used for bio-fuel.

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*Full Length Research Paper*

# Inefficiency in the international coffee market: The case of *Colombian arabica*

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**In this paper, we apply a nonstructural approach to analyze coffee price returns behavior over time. In particular, we use the Hinich portmanteau statistic test (H) to detect nonlinear dependence of the International Colombian Arabica Coffee price return for the period of June 29, 1990 to July 1, 2010 (5,219 observations). Our results sheds light that in 10 out of 173 episodes, a standard volatility model like GARCH for instance, does not entirely capture all the nonlinearity patterns that are present in the data. And we report some events whose arrival might have induced nonlinear dynamics. Our findings also suggest that the weak form of the efficient markets hypothesis (EMH) cannot be supported in this market.**

**Key words:** Colombian Arabica coffee price, Hinich portmanteau statistic test, nonlinear dependence.

## INTRODUCTION

Generalized Autoregressive Conditional Heteroskedasticity (GARCH)-type models have been widely applied in time-series econometrics to analyze time varying volatility in financial or economic data, such as stock market returns (Engle et al., 1987), inflation (Engle, 1982; Bollerslev, 1986) and commodity prices (Holt and Aradhyula, 1990). However, another thread of literature argues that these standard volatility models are not entirely appropriate for capturing the underlying process that generates the data. For example, Brooks and Hinich (1998) invalidate the GARCH specification for ten exchange rates denominated in Sterling; Hinich and Serletis (2007) show that a GARCH model does not capture the data structure of the Canadian dollar-U.S. dollar exchange rate; and Bonilla et al. (2006) demonstrate similar results for bond spreads in some Latin American markets. These authors arrive at their conclusions by applying general nonlinear dependence tests for data structure known as “pormanteau” tests. These tests measure the goodness-of-fit of a time series model based on the sum of squares of the first *m* residual autocorrelations. Portmanteau test statistics tests roots include those by Box and Pierce (1970). Other examples include the Ljung-Box test (Ljung and Box, 1978), BDS (Brock et al., 1996), the LM Engle (Engle, 1982) and the Hinich bicorrelation (Hinich, 1996; Hinich and Patterson, 1995). However, it is widely accepted that exchange rates follow some sort of nonlinear behavior that can be modelled by theshold autoregressive models (TAR) or smooth threshold autoregressive models (STAR) where the nonlinear function is many times of the exponential type.

One of the most relevant implications of not rejecting the hypothesis of nonlinear dependency in data structure is the failure of the weak form of the efficient market hypothesis (EMH): asset returns do not follow a random walk process. There is more than one way to test for the efficiency of markets. Even if a variable does not follow a

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**Table 1.** Coffee: supply and demand, 2010 (millions of 60 kg bags).

| | |
|---|---|
| Exportable production | 97.7 |
| Consumption | 94.8 |
| Balance | -0.24 |

Source: Economist Intelligence Unit.

random walk, the strong form of the EMH can still be valid. For instance, a memoryless stationary series consisting of a mean and white noise suffices. Otherwise, financial and economic variables would not be easy to forecast and, therefore, agents would be less likely to generate outstanding excess profits. By the same token, knowledge of changes in volatility is a key factor in financial or commodity markets. Investors, producers and policy makers require higher expected returns in exchange for holding riskier assets (Chan, 2010; Karali and Power, 2009). In this regard, the novelty of this paper consists of applying the Hinich portmanteau statistic, denoted by H, to test for nonlinearity in mean the return of the international Colombian Arabica coffee price. To the best of our knowledge, this is the first work that uses this specific statistic for analyzing commodity price returns. We report two main findings. First, we detect nonlinearities in 10 out of 173 windows; hence, we can conjecture inefficiency within the Colombian Arabica coffee market. Secondly, GARCH-type models are not adequate to analyze this market.

Previous works on commodity price behavior include those by Baillie and Myers (1991) and Power and Turvey (2010). The former concludes the GARCH models are also no adequate to model commodity futures market. The latters estimate the Hurst coefficients of the future price returns of 13 commodities, including coffee, quoted at the New York Board of Trade (NYBOT). Their results show dependency in the coffee price series over time and reject the hypothesis of Brownian motion for this particular commodity. Coffee is of the most relevant commodities in international markets. The main coffee producers are Brazil (top producing nation: 30% of global exportable production in 2010), Vietnam, Indonesia, Colombia and Mexico (FAO, 2005) (Table 1). Some of these economies strongly depend upon the production of such a commodity. For example, Vietnam´s coffee exports represented 12% of its total exports in 2002. Moreover, in the province of Dak Lak, a major Vietnamese producer, 95% of local income is related to the coffee industry (Fontenay and Leung, 2002). All over the world there are 26 million coffee farmers. There are two international coffee trade markets: the New York Coffee, Sugar and Cocoa Exchange (CSCE) and the London Stock Exchange (AIM) (FIRA, 2003). In these markets, several types of coffee are quoted such as Colombian Mild Arabicas, Brazilian naturals and Robustas. The former accounts of 60% of the world´s crop (The Economist, 2013). It is worth mentioning that coffee production is subject to weather shocks, government fostering plans, plant diseases (for example, leaf rust) and input prices that affect the market supply side (Fontenay and Leung, 2002), while new consumers such as Russia, Ukraine and the Gulf Cooperation Council Countries drive coffee demand shifts. And mature coffee markets such as the U.S., some European countries and Japan are saturated. But represent more than half of the world´s consumption (The Economist, 2013).

It is worth mentioning that 83% of American adults drink coffee, 63% of them on a daily basis (The Economist, 2013). Nevertheless, future demand is expected to increase in these consolidated markets because of rising home consumption (Economist Intelligence Unit, 2010). Thus, the combination of an elastic supply schedule and an inelastic demand schedule creates high volatility in this market (Metha and Chavas, 2004).

## METHODOLOGY

### The Hinich portmanteau test

The $H$ test is a modified version of the Box-Pierce portmanteau $Q$ statistic for autocorrelation and a third-order portmanteau statistic. A derivation of this test statistic is provided by Hinich (1996) and Hinich and Patterson (1995). By splitting observations into a set of nonoverlapped windows or frames of equal length, the H test identifies transcendent nonlinear periods. $x(t_k)$ denotes a time series sampled at a fixed rate, $t$ is an integer and $n$ is the window length. The $k^{th}$ window is denoted by $\{x(t_k + 0), x(t_k + 1), \ldots, x(t_k + n)\}$. The next window is denoted by $\{x(t_{k+1} + 0), x(t_{k+1} + 1), \ldots, x(t_{k+1} + n)\}$, where $t_{k+1} = t_k + n$. For each window, the null hypothesis is: $x(t_k)$ is a stationary process with bicorrelations equal to zero or pure white noise. The alternative hypothesis is: $x(t_k)$ is random with some bicorrelations different from zero. The bicorrelation is defined as $C_{xxx}(r, s) = E[x(t_k + 0)\, x(t_k + r)\, x(t_k + s)]$, where $0<r<s<L$ and $L$ is the number of lags in each window. All observations are standardized to $z(t_k) = (x(t_k) - x_k)/s_x$, where $s_x$ denotes the standard deviation within the window and $x_k$ is the median within each window. The H to detect nonlinear dependencies within a time series is equal to:

$$H = \sum_{s=2}^{L} \sum_{r=1}^{s-1} \left[ \frac{G^2(r,s)}{T - s} \right] \sim \chi^2((L-1)(L/2)), \tag{1}$$

Where $G(r, s) = (T\text{-}s)\, C_{zzz}(r, s)$. The number of lags per window is $L = T^c$, where $0<c<0.5$. $U = F(H)$ is uniformly distributed within the interval [0,1], and $F$ is distributed as $\chi 2$ with ($L$ - $1$) ($L/2$) degrees of freedom. To maximize the power of the proof and to guarantee asymptotic properties, Hinich (1996) suggests, based upon Monte Carlo simulations, to use $c = 0.4$ for the window size. A window is statistically significant if the null hypothesis is rejected below a threshold of 0.05. Calculations were obtained by running the program T23.

### The data

Our raw data consist of the daily Colombian Arabica coffee variety closing price (U.S. dollars per pound), $p_t$, on the New York Stock

**Table 2.** Descriptive statistics.

| | |
|---|---|
| Observations | 5,219 |
| Average | 0.001 |
| Lowest | -0.24 |
| Highest | 0.28 |
| Standard deviation | 0.02 |
| Asimetry | 0.59 |
| Kurtosis | 18.10 |
| *Jarque-Bera* test | 31,8067.20 |

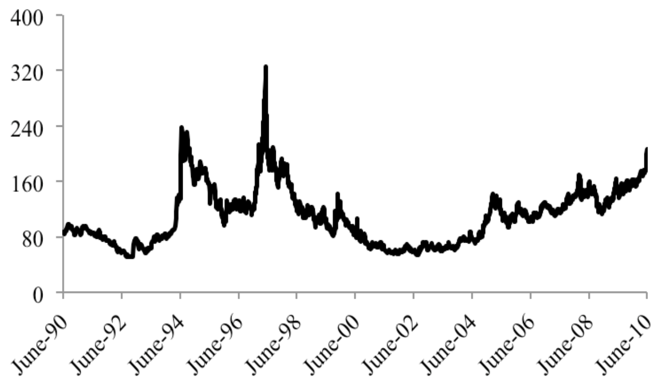


**Figure 1.** Colombian Arabica coffee price (US $ per pound).

Exchange, estimated and provided by the International Coffee Organization (ICO). The sample period covers almost 20 years, from June 29, 1990 to July 1, 2010. Calculations were obtained by running the program T23. The price series is transformed into daily log returns, $RC_t = \ln(p_t/p_{t-1})$. Descriptive statistics of our data are shown in Table 2. The price in this period experienced six clear swings: (1) a 33% decrease from June, 1990 to July, 1992; (2) a 310% increase from July, 1992 to July, 1994; (3) a 54% decrease from July, 1994 to December, 1995; (4) a 198% increase from December, 1995 to May, 1997; (5) an 81% decrease from May 1997 to April 2002; and (6) a 236% increase from April 2002 to June 2010 (Figure 1).

## RESULTS AND DISCUSSION

Before carrying out the *H* test, we test whether a GARCH specification is a valid characterization of the data, which we conclude that cannot be generated by a strongly stationary white noise process: In other words a GARCH model is unable to explain all observed nonlinearity in the coffee data. We follow the methodology of Brooks and Hinich (1998) and Hinich and Serletis (2007) to test whether our data fit a GARCH formulation. Such an outcome turns the *H* test pertinent. In order to perform the *H* test, serial correlation is removed in each window by fitting the return series to an AR(2) process according to Schwartz information criterion. Therefore, when rejecting the null hypothesis, given a significance level of 5%, pure noise is solely explained by nonlinearity of the time series (Bonilla et al., 2008). Data are divided into a set of 173 nonoverlapped windows, each 30 observations long. The number of observations in each window is $L = n^{0.4} = 5{,}219^{0.4}$, which is both long enough to apply the H statistic and short enough to capture nonlinearities (Brooks and Hinich, 1998). For 10 windows (5.78% of the total), we reject the null hypothesis of pure noise of Colombian Arabica coffee price returns and make reasonable conjectures on the financial and economic causes of these outcomes (Table 3). Over the analyzed period we identify that nonlinearites come up mainly from the supply side. In particular, weather frost, plant diseases and costs reduction policies through subsidies to coffee growers, as well as price increases due to the appreciation of local currencies.[1] We can conjecture that information asymmetries arise as a result of such shocks. For example, a production subsidy whose details have not been released may induce actions by actors involved in the coffee industry.

Our paper supports previous results based upon financial and economic time series, such as inflation volatility or stock price volatility, in invalidating the assumptions associated with the GARCH family models. These models cannot capture nonlinear dependencies to accurately predict future realizations. The patterns of the significant windows are depicted for the *1-p* values in Figure 2. We observe a few brief time periods of nonlinear behavior interspersed among long periods when a pure noise process drives coffee price returns.

## Conclusion

This paper analyzes nonlinearities in the return of Colombian Arabica coffee price. Our empirical results reject the hypothesis of pure white noise in 10 windows where nonlinear dependence arises. Therefore, innovations are not independent and identically distributed, and GARCH models estimates would be biased, for instance for option pricing as Power and Turvey (2010). Our results are consistent with Tomek (1994) who argues that transaction, information search and storage costs increase both autocorrelation and nonlinearities. To illustrate this, in June of 1994, Brazil was affected by climatic frost, which reduced the coffee supply and pushed the global market prices up. During this event, speculators expected higher stock prices (New York Times, 1994). In addition, information search costs in competitive markets induce prices to follow a stochastic process different from a random walk (Grossman and Stiglitz, 1980; Sunder, 1992). Some policy recommendations arise from our results such as increasing competition in the international coffee markets,

[1] In 2013, Arabica coffee price has fallen to the lowest levels in 4 years due to overcapacity on the supply side. Robusta type demand has increased dramatically in major markets.

**Table 3.** Dates of significant indication of nonlinearity.

| Series | Threshold | AR(p) fitness | # Windows | Windows with nonlinearities | Periods of nonlinear dependence | Key events |
|---|---|---|---|---|---|---|
| Rate of return of the coffee price | 0.05 | P = 2 | 173 | 10(5.78) | 10/03/94 | The ICO reached a new agreement with no regulatory economic clauses. |
| | | | | | 11/11/94 | Traders expected coffee shortage due to frosts in Brazil. There were pests in Colombia and due to internal conflicts Rwanda reduced its production. |
| | | | | | 07/24/95<br>09/01/95 | Colombia, Costa Rica, Honduras, Brazil, El Salvador and Nicaragua tried to pushed prices down by restricting their exports. |
| | | | | | 01/ 08/96<br>02/16/96 | Vietnam production increased due to lower costs and the use of more land pushing down international prices. Germany increased its consumption of Vietnamese coffee. |
| | | | | | 12/18/00<br>01/26/01 | It was expected that the Brazilian production surpass its historical trend. |
| | | | | | 06/04/01<br>07/13/01 | Central America, Colombia and Mexico sought to take joint actions to halt the decline in coffee prices |
| | | | | | 12/31/01 | The ICO and the WTO kept negotiations to review the rates of coffee.<br>There was an increase in coffee production originating in Vietnam, causing a fall in the international price. |
| | | | | | 02/08/02 | The ICO stated that small coffee farmers are being affected by the falling U.S. dollar and rising oil prices. |
| | | | | | 12/02/02 | Ends the Resolution 407, which is a program to improve coffee quality.<br>Overproduction arises because coffee has been replaced with poor quality coffee. |
| | | | | | 01/10/03 | The financial crisis in Argentina and other countries have frightened investors, which was reflected in a fall in coffee prices |
| | | | | | 12/24/08<br>01/02/09 | Despite the fact that production increased in Ethiopia, India and Vietnam, overall supply shifted down due to weather shocks in Latin America. In particular in Colombia. |
| | | | | | 05/11/09<br>06/19/09 | Due to weather shocks and higher production costs, Colombian coffee output is negatively affected. And high fertilizer prices. |
| | | | | | 10/26/09 | The ICO reported that Starbucks, one of the largest bulk buyers of coffee in Guatemala and Costa Rica, carried out their activities at a slower rate than normal switching to other markets with lower standards. |
| | | | | | 12/04/09 | The value of the U.S. dollar fell against the currencies of some coffee exporting countries during October like the Brazilian real, the Indian rupee and the Mexican peso, reducing the marginal benefit of the increase in prices. |

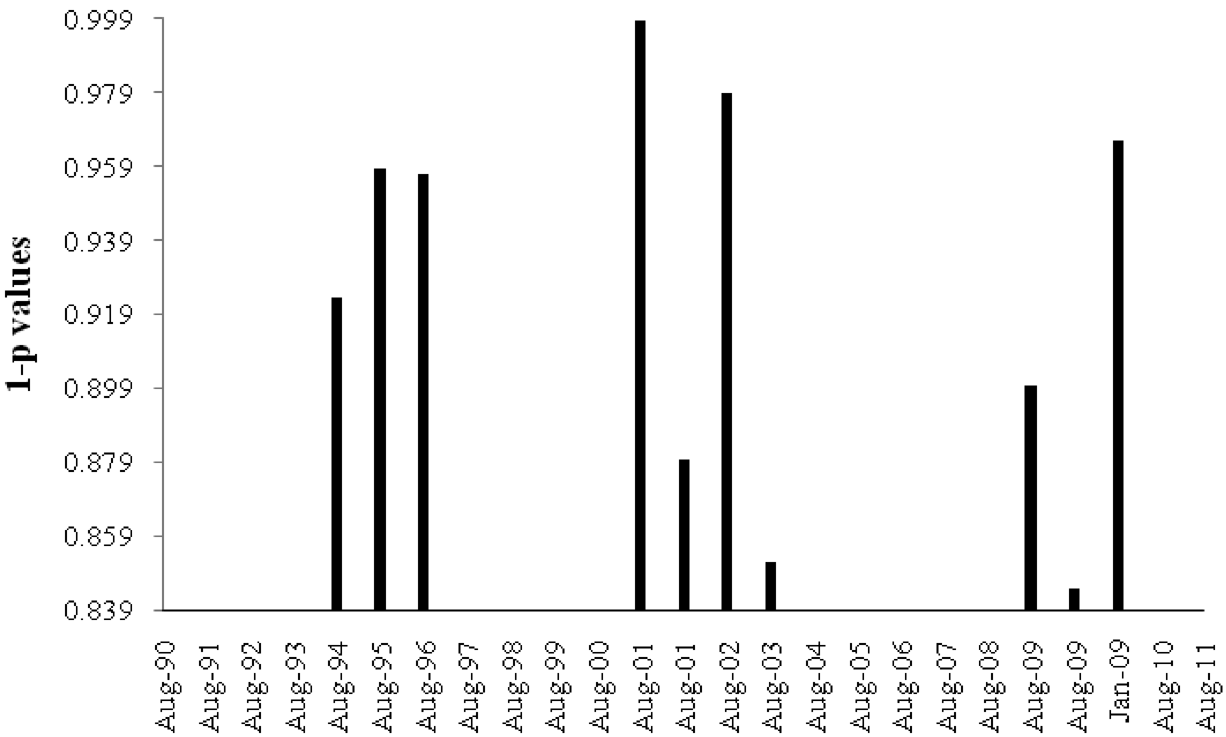


**Figure 2.** Significant Windows.

where the numbers of players, producers and wholesalers are limited indeed, for instance, Nestlé and Kraft (Salinas, 2000). We may also speculate that transport costs partially determine nonlinearities because, as Tomek (1994) argues, they reduce profits when producers are highly leveraged. Moreover, we reject the EMH, where all agents share the same information. However, it is plausible that an economic agent's actions could be driven by psychological factors that create nonlinear dependencies, as in Kahneman and Tversky's (1979) Prospect Theory. Nevertheless, for this to happen the market agent must have a dominant position in the market, either individually or through a cartel. Future work should compare our results to alternative nonlinearity tests. And finally, by understanding the dynamics of the price of this commodity over time is possible to design a derivative market to hedge the exposure to price fluctuations (Fontenay and Leung, 2002). Because Arabica coffee producers tend to be specialists, and do not plant other types of crops (The Economist, 2013).

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# Optimization of irradiation and storage temperature for delaying ripening process and maintaining quality of Alphonso mango fruit (*Mangifera indica* L.)

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**Alphonso mango fruit has high nutritional values, pleasant flavor, delicious taste as well as beautiful appearance and hence is known as the king of mango verities. The experiment was arranged from the 2008 and 2010 with 16 treatment combinations of irradiation dose (that is, 0.00, 0.20, 0.40, and 0.60 kGy) and stored at different storage temperatures viz., ambient at 27 ± 2°C and 60 to 70% RH, 9°C and 90% RH, 12°C and 90% RH, and Control atmospheric storage (12°C, $O_2$ 2%, $CO_2$ 3% and RH 90%). The fruits were exposed to gamma radiation from the source of $^{60}Co$. The two years collective data indicated that, the significantly minimum percent reduction in physiological loss in weight, reduced ripening percent, increased marketability of fruits, maximum total soluble solids, total and reducing sugars, and ascorbic acid content and minimum acidity were noted in 0.40 kGy gamma rays irradiated fruits stored at 12°C as compared to the other irradiated or unirradiated fruits stored at ambient condition and other storage environment. Suggestions were made for maximizing maintained physiological changes and quality by use of irradiation and adequate storage facilities for hygiene produce.**

**Key words:** Alphonso mango, irradiation, marketability, ripening, quality, storage temperature.

## INTRODUCTION

Asia accounts for 77% of global mango production and the Americas and Africa account for 13 and 19%, respectively (Pereira et al., 2010). India is the global leader in mango production (Tharanathan et al., 2006).The significant mission of any post harvest skill is to be raising the method by which decline of produce is controlled as much as possible during the stage between collect and consumption. Mango (*Mangifera indica* L., family Anacardiacae) is a tropical fruit and classified as climacteric fruit and ripens rapidly after harvest. Mango is generally harvested when physiologically mature and is allow ripening under suitable conditions of temperature and humidity. Therefore, if freshly harvested fruit is allowed to ripen at normal ambient conditions, ripening processes increase rapidly within few days, and quality point of view, it is not good. Mango is susceptible to chilling injury and an optimum temperature of 12 to 13°C is generally recommended (Gomez-Lim, 1993, Yimyong et al., 2011).

Irradiation is a physical process for the treatment of foods akin to conventional process like heating or freezing. It prevents food poisoning, reduces wastage to

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contamination, and at the same time preserves quality (Mahindru, 2009). However, issues related to quarantine and quality are the major stumbling blocks to trade, both national and international (Yadav et al., 2010). Therefore, the new knowledge is critical because it is important to maintain a balance between the optimum doses required to achieve safety and the minimum change in the sweetness of the fruit. In view of the aforementioned fact, it becomes quite clear that, investigation for mango fruit is very important for not only increase the soluble solids but also to control the conversion of starch into sugars for long time. The loss in sweetness of fruits is likely to reduce the marketability and quality of fruit drastically. Alphonso mangoes from India have captured sizeable Indian market and have very good export potential, but the protocol for their irradiation and post harvest storage yet needed to be standardized. In this paper the results of studies for standardization protocol of irradiation and storage are presented and discussed.

## MATERIALS AND METHODS

### Fruits and irradiation treatment

The experiment was set from 2008 to 2010 at Department of horticulture, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat. Export grade mangoes of cv. Alphonso were harvested from the University orchard. The selected mangoes from class I as per the quality parameters specified and described in “post harvest manual for mangoes” published by Agricultural Production and Export Development Authority (Anonymous, 2007). These fruits sorted by uniformity in size, maturity, and freedom from defects. The fruits were kept in plastic crates with cushioned material and transported to cold storage of Post Harvest Technology Unit, Navsari Agricultural University, Navsari (Gujarat) India. Than after, fruits were again sorted to remove those with spotty and having bad appearance. The individual fruit weight was from 250 to 350 g. The selected fruits were washed with chlorine water and after drying, the fruits were packed in corrugated Fiber board boxes cushioned (CFB) with tissue paper. The dimension of CFB box was 370 × 275 × 90 mm and gross weight of box with fruits was 3.0 kg. One box having nine fruits for each treatment and each treatment replicated thrice as per experimental design. The packed boxes kept in cold storage at 12°C for 8 h for pre-cooling treatment. The time gap between harvesting and pre-cooling was not more than 6 h.

After pre-cooling, fruits were transported to irradiation treatment in air conditioned vehicle. It was carried out at ISOMED plant, Board of Radiation and Isotope Technology, Bhabha Atomic Research Centre, Mumbai (India). The fruits were exposed to gamma radiation for different doses from the source radio isotope $^{60}$Co with energy 1.33 MeV. There were four irradiation doses that is, $I_1$ -0.00 kGy (Unirradiated), $I_2$ -0.20 kGy, $I_3$ -0.40 kGy, and $I_4$ -0.60 kGy. The time gap from pre-cooling to irradiation was not more than 9 h. After irradiation, fruits immediately transported to cold storage of university in air conditioned vehicle.

### Storage conditions

The boxes were kept in storage at different temperature as per s torage temperature treatments viz., ambient at 27 ± 2°C and 65 ± 5% relative humidity ($S_1$), 9°C and 90% relative humidity ($S_2$), 12°C and 90% relative humidity ($S_1$) and Control atmospheric storage at 12°C, $O_2$ 2%, $CO_2$ 3%, and 90% relative humidity ($S_1$). Post harvest biochemical changes of these fruits were studied by measuring the total soluble solids, sugars, acidity and ascorbic acid content of fruits.

### Measurement protocols

#### *Determination of physiological parameters*

**Physiological loss in weight (PLW) (%):** Four fruits from each treatment were weighted on 1st day of treatment and subsequently their weight was recorded from 4 to 6 day interval up to the end of shelf life. The PLW was expressed in percentage and calculated as follows;

$$\text{PLW \%} = \frac{W_1 - W_2}{W_1} \times 100$$

where, $W_1$ = initial weight and $W_2$ =final weight (Shankar et al., 2009).

Ripening percent: Ripening was measured by the 10 number of fruits having change in colour from greenish to yellow and soft in texture were counted from the 4th day of storage to the 6th day intervals up to the eating ripeness and expressed in percentage over total number of fruits taken for study.

**Marketable fruits percent:** The number of good quality and visibly sound fruits that can be marketed were counted and expressed as percentage over the total number of fruits at prescribed interval up to 90% fruits has marketability.

### Quality parameters

Total soluble solids were tested by using a digital hand refractometer PAL-1 (Atago, Japan). Sugar’s percentage was determined by titrimetric method of Lane and Eynon described by Rangana (1986). The method is based on the principle that, invert sugar or reducing sugar reduced the copper in the Fehling’s solution to red insoluble cuprous oxide. Non-reducing sugars were calculated by subtracting reducing sugar from total sugars. Method for titrable acidity by Rangana (1986) was adopted for estimation of titrable acidity. Ascorbic acid (mg/100 g) determination by the 2, 6-dichloroindophenol titrimetric method described by Rangana (1986) was adopted for estimation of the ascorbic acid content of fruits.

### Statistical analysis

Two years thrice replicated data obtained from the experiment was analyzed using ANOVA for completely randomizes deign with factorial concept. Significance differences among treatments were compared using the Fisher’s analysis of variance at the 5% probability level, technique as described by Panse and Sukhatme (1967). The data were subjected to appropriate transformation (arcsine) to meet the assumptions of normality.

## RESULTS AND DISCUSSION

### Physiological loss in weight

The data indicated that, the physiological loss in weight of fruits increased with the advancement of storage period and significantly influenced by irradiation and storage temperature. It was evident from the Table 1 that, the shelf life of fruits exposed with 0.40 and 0.60 kGy irradiation and stored at 9°C was extended more than 34 days. The minimum reduction in PLW was recorded in the fruits exposed with 0.40 kGy irradiation and stored at 9°C ($I_3S_2$) that is, 5.50% at 34$^{th}$ day, 4.45% at 28$^{th}$ day, 3.23% at 22$^{th}$ day, 2.35% at 16$^{th}$ day, 1.43% at 10$^{th}$ day, and 0.53% at 4$^{th}$ day of storage. The physiological loss in weight of fruits was possibly on account of loss of moisture through transpiration and utilization of some reserve food materials in the process of respiration (Mayer et al., 1960).

The physiological loss in weight of mango fruit was significantly influenced by the various exposed dose of gamma rays and different storage temperature. The irradiation significantly reduced physiological loss in weight during storage period over control which might be attributed to reduction in utilization of reserve food material in the process of respiration (Purohit et al., 2004). The delay in respiration rate as a result of irradiation was also reported by Singh and Pal (2009) in guava (*Psidium guajava* L.). Similar findings were also observed by Prasadini et al*.* (2008) and by El-Salhy et al*.* (2006) in mango.

Similarly, in the different storage conditions, the highest physiological loss in weight was observed in fruits subjected to ambient temperature and this was largely due to water loss through lenticles of fruits, which permit free water vapor movement (Salahddin and Kedar, 2006). Lower physiological loss in weight was noted in temperatures which might be due to lesser water vapour deficit compared to ambient condition and the low temperature which had slowed down the metabolic activities like respiration and transpiration (Mane and Patel, 2010). The observation accordance with the results in mango (Waskar and Masalkar, 1997), in banana (Nagaraju and Reddy, 1995), and in guava (Gutierrez et al,. 2002). The significantly minimum reduction in physiological loss in weight of mango fruits subjected to irradiation and stored at various temperatures that is, at 9 and 12°C and in CA (12°C) might be due to the mutual complementary effect of irradiation and low temperature.

## Ripening percent

Irradiated fruits significantly delayed the ripening process over unirradiated fruits irrespective of storage condition (Table 2) and not fully ripe up to 34$^{th}$ day of storage at 9°C. Rest of the treatments had more ripening and the other was discarded due to the lost of their shelf life. The fruits exposed to gamma rays (0.20 and 0.40 kGy) and stored at 9°C were showed at 86.21 and 84.23% ripening, respectively at 9°C ($S_3$) on 34 days of storage. Rest of the treatments had high ripening or discarded due to complete of their shelf life. Ripening percentage is a physiological process which designates the period from harvest until the fruits attain the stage of maximum consumer acceptability. The unirradiated mangoes had early ripeness whereas, gamma rays exposed mangoes that had a significantly delayed in ripening. The possible mechanisms that have been postulated include:

a) Irradiations results in decreased sensitivity to ripening action of ethylene.
b) Alteration in carbohydrates metabolism by regulating certain key enzymes, which interfere with production of ATP which is required for various synthetic processes during ripening (Udipi and Ghurge, 2010). Same findings were noted by Farzana (2005) in mango and by Aina et al. (1999) in banana. The decrease of ripening percent and increase in days for ripening at low temperature may be due to desirable inhibition of enzymatic activities leading to reduction in the respiration and ethylene production. These results were supported by Mann and Singh (1975) in mango and by Deka et al. (2006) in banana. The minimum and delayed ripening in fruits due to exposed to gamma rays and storage temperature at 9 and 12°C and in CA (12°C) storage compared to fruits unirradiated and kept at ambient temperature in present study might be due to the joint balancing effect of irradiation and low temperature.

## Marketable fruits percent

During storage, few treatments had 100% values for marketability and few had 0.00% marketability due to induction of senescence (Table 3). Irradiation significantly influenced the marketable fruit compared to unirradiated fruits at all conditions of the storage.

The highest marketable fruit (96.46%) was recorded in fruits exposed to 0.40 kGy gamma irradiation and kept at 12°C storage ($I_3S_3$) at 34 day of storage, and the rest of treatments had lower marketability or discarded due to the end of their shelf life. The marketable fruit was significantly influenced by various doses of gamma irradiation and storage temperatures. The possible reasons might be that, irradiation maintained water content in the fruit and low temperature coupled with high humidity in cold storage maintained the health of the fruits. These results were in conformity with the findings of El-Salhy et al*.* (2006) with respect to irradiation and Mane and Patel (2010) with respect to low temperature in mango.

## Total soluble solids

The data revealed that, total soluble solids in fruits were significantly affected by irradiation, storage temperature, and their interaction. It was evident from the data presented in Table 4 that significantly, the maximum total

**Table 1.** Optimization of irradiation and storage temperature for maintaining physiological loss in weight of Alphonso mango.

| Source | Physiological loss in weight days after storage (%) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | | | | | 10 | | | | | 16 | | | | |
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean |
| $S_1$ | 3.54 | 2.82 | 2.68 | 2.79 | 2.95 | 12.21 | 7.47 | 7.18 | 7.26 | 8.53 | 0.00 (1.65) | 10.31 (18.72) | 10.83 (19.20) | 11.50 (19.81) | 8.16 (14.84) |
| $S_2$ | 0.89 | 0.73 | 0.53 | 0.78 | 0.73 | 2.36 | 1.87 | 1.43 | 2.05 | 1.93 | 3.19 (10.28) | 2.97 (9.91) | 2.35 (8.82) | 3.10 (10.13) | 4.30 (9.79) |
| $S_3$ | 0.92 | 0.80 | 0.66 | 0.88 | 0.81 | 2.56 | 2.00 | 1.65 | 2.23 | 2.11 | 3.88 (11.34) | 3.10 (10.13) | 2.58 (9.23) | 3.38 (10.58) | 3.24 (10.32) |
| $S_4$ | 2.73 | 2.34 | 1.74 | 2.40 | 2.30 | 7.12 | 3.52 | 3.39 | 3.62 | 4.41 | 10.11 (18.53) | 5.28 (13.27) | 5.23 (13.20) | 5.48 (13.52) | 6.54 (14.63) |
| Mean | 2.02 | 1.67 | 1.40 | 1.71 | | 6.06 | 3.72 | 3.41 | 3.79 | | 4.30 (10.45) | 5.42 (13.01) | 5.25 (12.62) | 5.87 (13.52) | |
| Source | I | | S | | I X S | I | | S | | I X S | I | | S | | I X S |
| S. Em ± | 0.002 | | 0.004 | | 0.004 | 0.003 | | 0.003 | | 0.006 | 0.005 | | 0.005 | | 0.011 |
| CD ($P$≤0.05) | 0.005 | | 0.016 | | 0.011 | 0.009 | | 0.009 | | 0.017 | 0.016 | | 0.016 | | 0.031 |
| Source | 22 | | | | | 28 | | | | | 34 | | | | |
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean |
| $S_1$ | 0.00 (1.65) | 13.49 (21.54) | 12.66 (20.84) | 13.83 (21.83) | 9.10 (16.46) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) |
| $S_2$ | 4.66 (12.45) | 4.24 (11.87) | 3.23 (10.35) | 4.37 (12.05) | 4.12 (11.68) | 6.43 (14.68) | 5.47 (13.52) | 4.45 (12.16) | 5.78 (13.90) | 5.53 (13.57) | 7.74 (16.36) | 7.00 (15.33) | 5.50 (13.56) | 7.10 (15.44) | 6.84 (15.17) |
| $S_3$ | 4.83 (12.68) | 4.38 (12.07) | 3.43 (10.67) | 4.63 (12.42) | 4.32 (11.96) | 6.95 (15.27) | 5.70 (13.80) | 4.62 (12.41) | 5.99 (14.15) | 5.82 (13.91) | 0.00 (1.65) | 7.23 (15.59) | 5.72 (13.83) | 7.52 (15.91) | 5.12 (11.74) |
| $S_4$ | 13.33 (21.40) | 7.33 (15.69) | 6.96 (15.28) | 8.00 (16.42) | 8.91 (17.20) | 0.00 (1.65) | 9.31 (17.75) | 9.21 (17.65) | 9.51 (17.95) | 7.01 (13.75) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) |
| Mean | 5.70 (12.05) | 7.36 (15.29) | 6.61 (14.53) | 7.42 (15.43) | | 3.350 (8.31) | 5.12 (11.78) | 4.57 (10.97) | 5.32 (11.92) | | 1.94 (5.33) | 3.56 (8.55) | 2.81 (7.67) | 3.66 (8.66) | |
| Source | I | | S | | I X S | I | | S | | I X S | I | | S | | I X S |
| S. Em ± | 0.004 | | 0.004 | | 0.009 | 0.004 | | 0.005 | | 0.009 | 0.003 | | 0.003 | | 0.006 |
| CD ($P$≤0.05) | 0.013 | | 0.013 | | 0.026 | 0.013 | | 0.014 | | 0.026 | 0.009 | | 0.010 | | 0.019 |

Figure in parenthesis indicates ARC SINE transformed value. Where, I= Irradiation, S= Storage temperature.

soluble solids (17.69%) were recorded in fruits exposed to treatment $I_3$ (0.40 kGy) followed by treatment $I_2$ (0.20 kGy). The minimum total soluble solids (16.60%) were observed in treatment $I_1$(0.00 kGy). The higher total soluble solids in medium and lower dose irradiated fruits indicating

**Table 2.** Optimization of irradiation and storage temperature for maintaining ripening of Alphonso mango.

| Source | Ripening days after storage (%) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | | | | | 10 | | | | | 16 | | | | |
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean |
| $S_1$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 93.96 (75.73) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 23.49 (20.17) | 0.00* (1.65) | 71.68 (57.82) | 69.95 (56.73) | 72.96 (58.64) | 53.57 (43.7) |
| $S_2$ | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) |
| $S_3$ | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) |
| $S_4$ | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) |
| Mean | 8.36 (10.12) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | | 23.49 (20.17) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | | 0.00 (1.65) | 17.95 (15.69) | 17.49 (15.42) | 18.12 (15.90) | |
| Source | I | | S | | I X S | I | | S | | I X S | I | | S | | I X S |
| S. Em ± | 0.003 | | 0.003 | | 0.004 | 0.007 | | 0.007 | | 0.002 | 0.010 | | 0.010 | | 0.019 |
| CD ($P$≤0.05) | 0.010 | | 0.010 | | 0.014 | 0.021 | | 0.021 | | 0.007 | 0.028 | | 0.029 | | 0.055 |
| Source | 22 | | | | | 28 | | | | | 34 | | | | |
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean |
| $S_1$ | 0.00* (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00 (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.008 (1.65) | 0.00 (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00 (1.65) |
| $S_2$ | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 65.38 (53.94) | 29.98 (33.18) | 28.39 (32.19) | 47.16 (43.35) | 42.73 (40.66) | 0.00* (1.65) | 86.21 (68.29) | 84.23 (66.65) | 97.81 (81.56) | 66.91 (54.47) |
| $S_3$ | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 74.75 (59.81) | 33.16 (35.14) | 28.98 (32.55) | 57.47 (49.56) | 48.59 (44.27) | 0.00* (1.65) | 97.08 (80.25) | 96.40 (79.08) | 98.16 (82.31) | 72.91 (60.75) |
| $S_4$ | 77.30 (61. 52) | 69.53 (56.47) | 65.00 (53.71) | 73.26 (58.84) | 71.27 (57.63) | 0.00* (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00 (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00* (1.65) | 0.00 (1.65) |
| Mean | 19.33 (16.62) | 17.38 (15.36) | 16.25 (14.67) | 18.32 (15.95) | | 35.03 (29.26) | 15.79 (17.91) | 14.34 (17.01) | 26.16 (24.06) | | 0.00 (1.65) | 45.82 (37.90) | 45.16 (37.23) | 48.99 (41.74) | |
| Source | I | | S | | I X S | I | | S | | I X S | I | | S | | I X S |
| S. Em ± | 0.01 | | 0.02 | | 0.02 | 0.09 | | 0.04 | | 0.02 | 0.03 | | 0.03 | | 0.06 |
| CD ($P$≤0.05) | 0.03 | | 0.06 | | 0.06 | 0.27 | | 0.14 | | 0.05 | 0.09 | | 0.09 | | 0.17 |

Figure in parenthesis indicates ARC SINE transformed value 2 * indicate fruits completely discarded Where, I = irradiation, S = storage temperature.

the induction of ripening process due to irradiation (Sudto et al. 2005). These results were in accordance with the findings of El-Salhy et al. (2006) in mango, Wall (2007) in banana, Singh and Pal (2007) in guava, and Silva et al.(2010) in Caja (*Spondias sp.*) fruit. Under various storage

**Table 3.** Optimization of irradiation and storage temperature for maintaining marketing of Alphonso mango.

| Source | Marketable fruits days after storage (%) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | | | | | 10 | | | | | 16 | | | | |
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean |
| $S_1$ | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 8.36 (1.65) | 97.66 (81.19) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 99.41 (86.53) | 0.00 (1.65) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 75.00 (60.90) |
| $S_2$ | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) |
| $S_3$ | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) |
| $S_4$ | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) |
| Mean | 8.36 (10.12) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | | 99.41 (86.53) | 100 (88.31) | 100 (88.31) | 100 (88.31) | | 75.00 (60.90) | 100 (88.31) | 100 (88.31) | 100 (88.31) | |
| Source | I | | S | | I X S | I | | S | | I X S | I | | S | | I X S |
| S. Em ± | 0.003 | | 0.003 | | 0.004 | 0.03 | | 0.03 | | 0.07 | 0.02 | | 0.02 | | 0.03 |
| CD (*P*≤0.05) | 0.010 | | 0.010 | | 0.014 | 0.10 | | 0.10 | | 0.20 | 0.05 | | 0.05 | | 0.10 |

| Source | 22 | | | | | 28 | | | | | 34 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean |
| $S_1$ | 0.00 (1.65) | 88.80 (70.43) | 89.33 (70.91) | 85.96 (67.97) | 66.02 (52.74) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) |
| $S_2$ | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 84.54 (66.82) | 95.94 (78.36) | 100 (88.31) | 94.00 (75.80) | 93.62 (77.32) | 0.00 (1.65) | 70.45 (57.05) | 74.22 (59.46) | 69.11 (56.21) | 53.45 (43.59) |
| $S_3$ | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 98.44 (82.83) | 100 (88.31) | 100 (88.31) | 100 (88.31) | 99.61 (86.94) | 74.16 (59.42) | 94.13 (75.94) | 96.46 (79.12) | 92.00 (73.54) | 89.19 (72.00) |
| $S_4$ | 94.04 (78.85) | 100 (88.31) | 100 (88.31) | 96.17 (78.70) | 97.55 (82.79) | 59.41 (50.41) | 70.89 (57.32) | 84.23 (66.57) | 69.27 (56.31) | 70.95 (57.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) | 0.00 (1.65) |
| Mean | 73.51 (63.53) | 97.20 (83.84) | 97.33 (83.56) | 95.53 (80.82) | | 60.60 (50.43) | 66.71 (56.41) | 71.06 (61.21) | 65.82 (55.52) | | 18.54 (16.10) | 41.15 (34.07) | 42.67 (35.47) | 40.28 (33.26) | |
| Source | I | | S | | I X S | I | | S | | I X S | I | | S | | I X S |
| S. Em ± | 0.003 | | 0.003 | | 0.004 | 0.03 | | 0.03 | | 0.07 | 0.02 | | 0.02 | | 0.03 |
| CD (*P*≤0.05) | 0.010 | | 0.010 | | 0.014 | 0.10 | | 0.10 | | 0.20 | 0.05 | | 0.05 | | 0.10 |

Figure in parenthesis indicates ARC SINE transformed value, I = irradiation, S= storage temperature.

conditions, the maximum total soluble solids (18.04%) were recorded by fruits stored under treatment $S_3$ (12°C) followed by treatment $S_4$ (CA at 12°C). The minimum total soluble solids (16.62%) were observed under treatment $S_1$ (9C). The total soluble solids in fruits at ripening were

**Table 4.** Optimization of irradiation and storage temperature for maintaining quality of Alphonso mango.

| Source | TSS (%) | | | | | Total sugars (%) | | | | | Reducing sugars (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean |
| $S_1$ | 15.86 | 17.13 | 17.36 | 16.14 | 16.62 | 13.12 | 13.76 | 13.87 | 13.48 | 13.56 | 3.45 | 3.93 | 4.12 | 3.67 | 3.79 |
| $S_2$ | 16.12 | 17.27 | 17.36 | 16.57 | 16.83 | 13.52 | 14.15 | 14.47 | 13.81 | 13.99 | 3.92 | 4.39 | 4.68 | 4.17 | 4.29 |
| $S_3$ | 17.62 | 18.27 | 18.46 | 17.82 | 18.04 | 14.21 | 14.97 | 15.12 | 14.36 | 14.67 | 4.58 | 5.13 | 5.20 | 4.88 | 4.95 |
| $S_4$ | 16.83 | 17.44 | 17.57 | 17.34 | 17.30 | 13.68 | 14.05 | 14.61 | 13.95 | 14.07 | 4.00 | 4.52 | 4.97 | 4.42 | 4.48 |
| Mean | 16.60 | 17.53 | 17.69 | 16.96 | | 13.63 | 14.24 | 14.52 | 13.90 | | 3.99 | 4.49 | 4.74 | 4.291 | |
| Source | I | | S | | I X S | I | | S | | I X S | I | | S | | I X S |
| S. Em ± | 0.009 | | 0.009 | | 0.017 | 0.007 | | 0.007 | | 0.014 | 0.004 | | 0.004 | | 0.009 |
| CD ($P$≤0.05) | 0.026 | | 0.025 | | 0.049 | 0.021 | | 0.021 | | 0.041 | 0.013 | | 0.013 | | 0.026 |

| Source | Non-reducing sugars (%) | | | | | Acidity (%) | | | | | Reducing sugars (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean | $I_1$ | $I_2$ | $I_3$ | $I_4$ | Mean |
| $S_1$ | 9.67 | 9.82 | 9.74 | 9.80 | 9.76 | 0.262 | 0.215 | 0.193 | 0.244 | 0.228 | 9.12 | 9.20 | 9.45 | 9.12 | 9.23 |
| $S_2$ | 9.60 | 9.76 | 9.79 | 9.79 | 9.63 | 0.240 | 0.194 | 0.182 | 0.230 | 0.211 | 9.14 | 9.41 | 9.53 | 9.23 | 9.33 |
| $S_3$ | 9.63 | 9.84 | 9.91 | 9.47 | 9.71 | 0.182 | 0.162 | 0.145 | 0.169 | 0.164 | 9.12 | 10.24 | 10.58 | 9.98 | 9.98 |
| $S_4$ | 9.68 | 9.53 | 9.64 | 9.52 | 9.59 | 0.220 | 0.179 | 0.171 | 0.215 | 0.196 | 9.20 | 9.78 | 9.87 | 9.41 | 9.57 |
| Mean | 9.64 | 9.74 | 9.77 | 9.61 | | 0.226 | 0.187 | 0.172 | 0.214 | | 9.15 | 9.66 | 9.86 | 9.43 | |
| Source | I | | S | | I X S | I | | S | | I X S | I | | S | | I X S |
| S. Em ± | 0.005 | | 0.005 | | 0.011 | 0.0003 | | 0.0003 | | 0.0006 | 0.005 | | 0.005 | | 0.010 |
| CD at 5 % | 0.016 | | 0.016 | | 0.031 | 0.0008 | | 0.0008 | | 0.0017 | 0.015 | | 0.015 | | 0.029 |

Where, I = irradiation, S = storage temperature.

significantly higher in fruits stored at lower temperature storage as compared to minimum at ambient temperature (Table 4).This might be that, the accumulation of total soluble substances due to desired ripening. These findings were also in accordance with the findings of Roy and Joshi (1989) in mango, Plaza et al. (1992) in papaya, and Hussein et al., (1998) in guava. Jointly the maximum total soluble solids (17.36%) were recorded in fruits exposed to gamma rays at 0.40 kGy and stored at 12°C ($I_3S_3$).The minimum total soluble solids (15.86%) were recorded in unirradiated ambient stored ($I_1S_1$) fruits at the time of full ripening (Table 4). The maximum total soluble solids was recorded in fruits exposed to various dose of irradiation and stored at 12 and 9°C and in CA (12°C) storage compared to unirradiated fruits stored at ambient temperature in present study might be due to the beneficial effects of irradiation dose and storage temperature.

## Sugars (percent)

### *Effect of irradiation*

The data revealed that, total sugar percent of fruits was significantly affected by irradiation, storage temperature and their interaction. It was evident from the data presented in Table 4 that significantly the maximum total sugars (14.52%) were observed in fruits exposed to treatment $I_3$ (0.40 kGy). The minimum total sugars (13.63%) were observed in treatment $I_1$ (0.00 kGy). The maximum reducing sugar percent (4.95) was observed in fruits exposed to treatment $I_3$ (0.40kGy) whereas, minimum reducing sugars (3.795%) were observed in treatment $I_1$ (0.00 kGy). The maximum non-reducing sugars (9.77%) were observed in fruits exposed to treatment $I_4$ (0.60 kGy) followed by treatment $I_2$ (0.20 kGy) compared to minimum (9.61) in unirradiated. The higher rate of increase in sugars content in irradiated fruits might be due to maintained ripening and corresponding greater conversion of starch into sugars. Irradiation might also accelerate the rate of gluconeogenesis (Wall, 2007). Similar findings had been observed by Beyers and Thomas (1979) in mango and Kovacs et al. (1994) in apple.

***Effect of storage temperature***

It was cleared from the data presented in Table 4 that significantly maximum total sugar (14.61%) was recorded by fruits stored under treatment $S_3$ (12°C), and minimum (13.56%) were under treatment $S_1$. The maximum reducing sugar percent (4.95) was recorded in fruits stored under treatment $S_3$ ($12^0$C). The minimum reducing sugars (3.79%) were observed under ambient temperature ($S_1$). The maximum non-reducing sugar (9.71%) was recorded in fruits stored under treatment $S_3$ (12°C) compared to minimum (9.63%) were observed under at 9°C ($S_4$). The increase in the total and reducing sugars were maintained till the end of shelf life in storage temperature at 12 and 9°C and in CA (12°C) storage might be due to suppression in the respiration rate and enzyme activities and therefore, the conversion of starch into sugars might had been at slower rate and reaching maximum at the end of storage. Same trend of results were noticed by Narayana and Singh (2000) in mango and Purwoko et al. (2002) in banana.

***Combined effect of irradiation and storage temperature***

Results obtained during experimentation indicating (Table 4) significantly that, the maximum total sugars (15.12%) were recorded in fruits exposed to gamma rays at the dose of 0.40 kGy and stored at 12°C ($I_3S_3$. The minimum total sugar (13.12%) was recorded in unirradiated ambient stored ($I_1S_1$) fruits at the time of complete ripening. The maximum reducing sugar (5.20%) was recorded in fruits exposed to gamma rays at the dose of 0.40 kGy and stored at 12°C ($I_3S_3$). Results obtained during experimentation indicating that, maximum non-reducing sugar (9.91%) was recorded in fruits exposed to gamma rays at the dose of 0.40 kGy and stored at 12°C ($I_3S_3$) whereas, minimum non-reducing sugar (9.67%) was recorded in unirradiated ambient ($I_1S_1$) stored fruits at the time of full ripening. The maximum total and reducing sugar were recorded in fruits exposed to various doses of irradiation and storage temperature of 12 and 9°C and in CA (12°C) storage compared to unirradiated fruits stored at ambient temperature in present study which might be due to the beneficial effects of irradiation dose and storage temperature. The total and reducing sugars increased during storage but the non-reducing sugars did not exhibit same pattern during storage, since it represented a product of subtraction of reducing sugars from total sugars.

**Titrable acidity**

The data revealed that, acidity fruits was significantly affected by irradiation, storage temperature and their interaction. It was evident from the Table 4 that, significantly minimum acidity (0.172%) was observed in fruits exposed to treatment $I_3$ (0.40 kGy) compared to maximum (0.226%) was observed in treatment $I_1$ (0.00 kGy). The reduction in acidity by irradiation reflects a possible decrease in organic acids (Wall, 2007). These results were in accordance with the findings of Upadhyay (1992) and El-Salhy et al. (2006) in mango and Sornsrivichai at el. (1990) in apple. Under storage conditions it is cleared from the Table 4 that, significantly the minimum acidity (0.164%) was recorded in fruits stored under treatment $S_3$ (12°C). The maximum acidity (0.228%) was observed under treatment $S_1$ (ambient temperature). The lower acidity at low temperature might be due to utilization of acids in the process of respiration during ripening and reduced supply of sugars (Mane and Patel 2010). Same findings noted by Plaza et al. (1992) in papaya and Singh and Pal (2007) in guava. Combined results obtained during experimentation indicating that, significantly the minimum acidity (0.145%) was recorded from fruits exposed to gamma rays at the dose of 0.40 kGy and stored at 12°C ($I_3S_3$) whereas, maximum acidity (0.262%) was recorded in unirradiated ambient stored ($I_1S_1$) fruits at the time of full ripening. The minimum acidity was recorded in fruits exposed to various dose of irradiation and stored at 12 and 9°C and in CA (12°C) storage as compared to unirradiated fruits stored at ambient temperature in present study might be due to the beneficial effects of irradiation dose and storage temperature.

**Ascorbic acid**

Significantly the maximum ascorbic acid (9.86 mg/100g pulp) was observed in fruits exposed to 0.40 kGy ($I_3$), and the minimum ascorbic acid (9.15 mg/100 g pulp) was observed in treatment $I_1$ (0.00 kGy) (Table 4). The higher ascorbic acid due to irradiation was in accordance with the findings of Dhakar et al. (1966) in mango and Bhushan and Thomas (1990) in apple. Significantly the maximum ascorbic acid (9.98mg/100g pulp) was recorded in fruits stored under treatment $S_3$ (12°C) as compared to minimum (9.23 mg/100 g pulp) was observed under treatment $S_1$. Also, significantly the maximum ascorbic acid was recorded in fruits stored at 12 and 9°C temperature and in CA (12°C) storage whereas, minimum ascorbic was recorded under ambient temperature stored fruits (Table 4). Same findings was noted by Ray and Joshi (1989) in mango and Plaza et al. (1992) in papaya.

## RESULTS

Results obtained (Table 4) during the experimentation indicates that, significantly the maximum ascorbic acid (10.58 mg/100 g pulp) was recorded in fruits exposed to gamma rays at 0.40 kGy and stored at 12°C ($I_3S_3$) whereas, minimum ascorbic acid (9.12 mg/100 g pulp) was recorded in unirradiated ambient stored ($I_1S_1$) fruits at the time of complete ripening. The fruits of Alphonso mango subjected to 0.40 kGy gamma rays irradiation subsequently stored at 9°C delayed the ripening process which maintained lower percentage of physiological loss in weight and ripening percentage, higher percentage of marketable fruits, and increase the shelf life for longer period. The data also indicated that, the maximum total soluble solids, total, and reducing sugars, ascorbic acid, and minimum acidity were noted in 0.40 kGy gamma rays irradiated fruits were stored at 12°C as compared to unirradiated fruits stored at ambient condition at ripening stage.

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# Influence of nitrogen on the production characteristics of ruzi grass

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**Understanding the action of the nitrogen (N) in grasses can aid in pasture management and increase the efficiency of this nutrient. The objective of this study was to determine the influence of N rates and of the available N from the previous crop on *Brachiaria ruziziensis* cv. Comum. The experiment was conducted in a greenhouse. The treatments were arranged in a 2×4 factorial design and were distributed according to a fully randomized block design with four replications. Two N rates (0 and 15 mg dm$^{-3}$) were applied at grass planting and four N rates were applied as topdressing after the first cutting (0, 15, 30 and 45 mg dm$^{-3}$). The grass was cut twice above-ground. The comparison between N rates applied at planting was made using F test, and the degrees of freedom of the N rates applied as topdressing were broken down into orthogonal polynomials. The N rate of 15 mg dm$^{-3}$ applied at planting the ruzi grass promoted increases in the numbers of leaves and shoot dry matter production. During the second growth, N rates (15, 30 and 45 mg dm$^{-3}$) applied as topdressing increased the number of leaves and the shoot dry matter production. The available N from the previous crop (soybean) was sufficient for the initial tillering of the ruzi grass. This study showed that the correct management of N fertilization is necessary for ruzi grass when grown after a previous crop (soybean).**

**Key words:** Available nitrogen, forage plants, management of nitrogen, residual nitrogen.

## INTRODUCTION

The use of soybeans as a supplier of nitrogen (N) to succeeding crops in direct planting in straw is widely discussed because legumes in general are able to fix from 11 to 336 kg ha$^{-1}$ of N per year (Havlin et al., 1999). By taking advantage of the available N from the previous crop (soybean), one method has been developed where grasses, especially *Brachiaria ruziziensis* cv. Comum (ruzi grass), are sown between rows of the second-crop corn so as to provide nutrients to the corn. Thus, the fertilization prioritizes the second-crop corn without considering that the limiting factor for the growth of herbage species is often the level of available N (Bland, 1968).

Ruzi grass has good drought tolerance. It requires soils with high fertility, such as Oxisols, and will tolerate acidic soils. It suppresses weeds and is useful for erosion control in areas where it grows well, but needs good drainage (it does not tolerate flooding). Finally, it responds well to nitrogen, either inorganic or from legumes (Cook et al., 2005).

Nitrogen is necessary for rapid growth of forage, and is an essential component of plant proteins. Since the amount of available N from the soil is typically less than the plants need, N fertilizer can be effectively used to increase forage productivity in pastures, as needed (Hancock et al., 2011). Nitrogen utilization efficiency can

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be 9 to 28 kg of dry matter per 1 kg of N applied. After N fertilizer is applied, N is rapidly absorbed into plants and growth is stimulated via improvement of root systems and photosynthetic activity. Responses of grassland to nitrogen vary according to several factors, such as type of N applied, application rate and timing (Sun et al., 2008).

Understanding the action of the N in the soil and grasses can aid in pasture management and increase the efficiency of this nutrient, especially knowing that the reduction of N availability is a major cause of tropical pasture degradation (Cao et al., 2012).

We hypothesize that the N doses usually applied at planting and in topdressing of second-crop corn could be also effective on *B. ruziziensis* cv. Comum. We tested this hypothesis under controlled conditions. The objective of this study was to determine the influence (i) of N rates applied at planting (15 mg dm$^{-3}$) and in topdressing (0, 15, 30 and 45 mg dm$^{-3}$) of second-crop corn and (ii) of the available N from the previous crop (soybean) on the productive characteristics of *B. ruziziensis* cv. Comum.

## MATERIALS AND METHODS

This study was carried out in a glass greenhouse under controlled conditions to avoid interferences of other nutrients (e.g., transfer of nutrients from other areas via animal manure) and ensure an adequate water supply and ambient temperature for normal plant growth.

The experiment was carried out in the summer of 2011 with soil from an area cultivated with soybean-second-crop corn rotation under a tillage system during 10 years, located in the municipality of Itapetininga (23°35'08"S; 48°02'50"W), São Paulo State, Brazil. The soil is an Oxisol (dystrophic red Latosol). The soil was collected immediately after the soybean harvest and before planting the second-crop corn, at a depth of 0 to 20 cm. The soil was dried, sieved, weighed and then placed in ceramic pots with capacity of 3.6 dm$^3$.

The chemical soil analysis showed the following results: pH in $CaCl_2$=5.8; organic matter content=38.0 mg dm$^{-3}$; P (resin)=132.0 mg dm$^{-3}$; K (resin)=4.9 mmol$_c$ dm$^{-3}$; Ca (resin)=60.0 mmol$_c$ dm$^{-3}$, Mg (resin)=16.0 mmol$_c$ dm$^{-3}$; Al=0 mmol$_c$ dm$^{-3}$; H + Al=31.0 mmol$_c$ dm$^{-3}$; $SO_4$=6.0 mg dm$^{-3}$; base saturation (BS)=80.9 mmol$_c$ dm$^{-3}$; cation exchange capacity (CEC)=112.0 mmol$_c$ dm$^{-3}$; V=72.0%; B=0.19 mg dm$^{-3}$; Cu=3.4 mg dm$^{-3}$; Fe=15 mg dm$^{-3}$; Mn=3.0 mg dm$^{-3}$ and Zn= 3.0 mg dm$^{-3}$. These results showed that correction for soil acidity and fertilization with macro- and micronutrients was not necessary before sowing the grass (Werner , 1986).

Based on the observations of Batista et al. (2011), the treatments were arranged in a 2×4 factorial design, where two N rates (0 and 15 mg dm$^{-3}$) were applied at planting the ruzi grass, and four N rates (0, 15, 30 and 45 mg dm$^{-3}$) were applied as topdressing after the first cutting. These N rates corresponded to those generally used for supplying N at planting and topping of second-crop corn in Brazil. Therefore, the following combinations were constituted: 0, 0; 0, 15; 0, 30; 0, 45; 15, 0; 15, 15; 15, 30 and 15, 45 mg dm$^{-3}$. These combinations were distributed in a greenhouse in a fully randomized block design with four replications.

Five plants of Ruzi grass were grown per pot. On the day of sowing, initial N treatment of 15 mg dm$^{-3}$ was applied in the form of an ammonium nitrate solution. The treatments without initial N received only distilled water.

At 19 days after the germination of the ruzi grass, the counting of leaves and tillers started. These counts were performed every seven days. The tillers were counted as soon as they presented a fully expanded leaf with a visible ligule, while the new leaves were also counted when they presented a visible ligule. The tillers were marked with plastic-coated wires, and inert ink was used for identification of the leaves.

At 39 days after the germination, the first cutting was performed, after which topdressing fertilization was applied to provide 40 mg dm$^{-3}$ of $P_2O_5$ in the form of potassium dihydrogen phosphate ($KH_2PO_4$), 83 mg dm$^{-3}$ of $K_2O$, with 384 mg dm$^{-3}$ in the form of $KH_2PO_4$ and 186.3 mg dm$^{-3}$ in the form of potassium chloride (KCl). A supply of potassium was necessary due to the appearance of potassium deficiency symptoms during the first growth, and phosphorus was provided to avoid limiting the response of the plants to the N doses. On the day following the cutting, N rates of 0, 15, 30 and 45 mg dm$^{-3}$ were applied as topdressing in the form of ammonium nitrate to provide the planned N.

Approximately eight days after the first cutting, chlorosis was observed in young leaves, accompanied by narrow dark green bands. As a result of these observations, 6 mg dm$^{-3}$ of manganese was applied as manganese sulphate monohydrate ($MnSO_4.H_2O$), and 15 mg dm$^{-3}$ of sulphur was applied in the form of potassium sulphate ($K_2SO_4$).

The second cutting occurred 27 days after the first, and the counting of the tillers and leaves was resumed eight days after the first cutting. Thus, the first growth was 39 days after germination and the second growth was 27 days after the first cutting.

After each cutting, each shoot was separated into: (a) Two newly expanded leaves; (b) Emerging leaves; (c) Mature leaves and (d) Stem + sheath. All these materials collected were dried in a forced air oven at 65°C until a constant weight was achieved.

The production of the total dry mass in the shoots was determined by the sum of the dry mass of the newly expanded leaves, emerging leaves, mature leaves and stem + sheaths. The leaf/stem ratio was determined using the dry mass production data of the leaf and stem fractions.

The comparison between N rates applied at planting was done using F test, and the degrees of freedom of the N rates applied as topdressing were broken down into orthogonal polynomials.

## RESULTS AND DISCUSSION

### Tillering of ruzi grass

The available N from the previous crop (soybean) was sufficient for the initial tillering of ruzi grass because in the first growth of the ruzi grass, the number of tillers did not differ between the N rates applied at planting (Table 1).

This result demonstrated that the available N from the previous crop (soybean) permitted the partial substitution of the N fertilizer. Legumes in general create very good conditions for subsequent crops, the main reason being the large amount of organic matter ploughed in Sarunaite et al. (2006). Thus, it is necessary to adapt the available N from the soybeans and the N from the fertilizer, according to the demand of the grass (Halvorson et al., 1999). In other words it is necessary to take care of adequate supply of N to the grass ruziziensis.

The number of tillers in the second growth of the Ruzi grass indicated that when the N was deficient, the development of the tillers was inhibited, but when the supply of N to the plants grown individually was increased,

**Table 1.** Number of tillers and leaves, total dry mass of shoots and leaf/stem ratio of ruzi grass as a function of nitrogen applied at planting (first growth).

| N at planting (mg dm$^{-3}$) | Number | | Dry mass (g/pot) | Leaf/stem |
|---|---|---|---|---|
| | Tillers | Leaves | | |
| 0 | 20.40$^{a}$ | 85.25$^{b}$ | 10.18$^{b}$ | 2.07$^{a}$ |
| 15 | 20.30$^{a}$ | 96.87$^{a}$ | 13.13$^{a}$ | 2.07$^{a}$ |
| Means | 20.35 | 91.06 | 11.65 | 2.07 |
| CV (%) | 13.92 | 7.01 | 8.45 | 13.13 |

Means followed by different lowercase letters in the column differ by F test (P ≤ 0.05) for each variable.

**Table 2.** Numbers of tillers and leaves of ruzi grass grown in soil from cultivation of soybean planting system as a function of nitrogen applied at planting and topdressing (second growth).

| N at coverage (mg dm$^{-3}$) | Number of tillers | | | Number of leaves | | |
|---|---|---|---|---|---|---|
| | N at planting (mg dm$^{-3}$) | | | N at planting (mg dm$^{-3}$) | | |
| | 0 | 15 | Means | 0 | 15 | Means |
| 0 | 29.50 | 45.00 | 37.25 | 63.25 | 104.25 | 104.25 |
| 15 | 29.25 | 44.00 | 36.62 | 83.75 | 120.50 | 102.12 |
| 30 | 36.75 | 52.25 | 44.50 | 129.75 | 156.00 | 142.87 |
| 45 | 44.50 | 51.50 | 48.00 | 130.50 | 162.25 | 146.37 |
| Means | 35.00$^{B}$ | 48.19$^{A}$ | | 101.81$^{B}$ | 135.75$^{A}$ | |
| F test | | | | | | |
| Linear effect | | | ** | | | ** |
| Quadractic effect | | | ns | | | ns |
| CV (%) | 12.60 | | | | 9.28 | |

Means followed by different capital letters for each variable differ by the F test (P≤ 0.05). **, P≤ (0.01). $^{ns}$, not significant (P≥0.05).

the number of tillers per plant increased, in line with the findings of Langer (1963). This result occurred because during the second growth significant differences were observed between the N rates that were applied at planting of the grass, where the N dose of 15 mg/dm$^3$ resulted in a greater production of tillers (Table 2).

In the second growth, there was no interaction between the N rates applied at planting and those applied as topdressing (Table 2). An isolated response was observed, but only for the N rates that were applied as topdressing, fitting a linear regression equation (Figure 1a).

In second growth there was an average two-fold increase in the number of tillers, indicating that during the initial growth period, the soil N was sufficient for growth of the grass. However, during the second growth, N supplementation was necessary to increase the number of tillers. These results demonstrated the need to properly manage N fertilization associated with the use of legumes in the system of crop rotation using soybean as the previous crop.

According to Garcez Neto et al. (2002) N influences the activation of dormant buds and accelerates the tissue flow in individual tillers, increasing the turnover of leaves and tillers, which favors the production of forage. Since the flow of fabric appears to be influenced by the processes of absorption and partition recycling of nitrogen (Gastal et al, 1992). However, these results showed that the use of a legume alone in the system may not promote sufficient N accumulation for ruzi grass intercropped with second-crop corn, as also reported by Papendick et al. (1987).

## Number of ruzi grass leaves

With respect to the number of leaves in the first growth, differences were observed between the N rates at the planting, where the addition of 15 mg dm$^{-3}$ promoted a 10% increase in the number of leaves (Table 1). The increase in the number of leaves in the first growth occurred because variation in the emergence of the leaves of the grasses fertilized with N are related to the direct effect that N has on the flow of cells within the meristematic region (Paiva et al., 2012).

In the second growth of the ruzi grass, the number of leaves exhibited differences between the N rates at planting, where supplying 15 mg dm$^{-3}$ of N promoted a

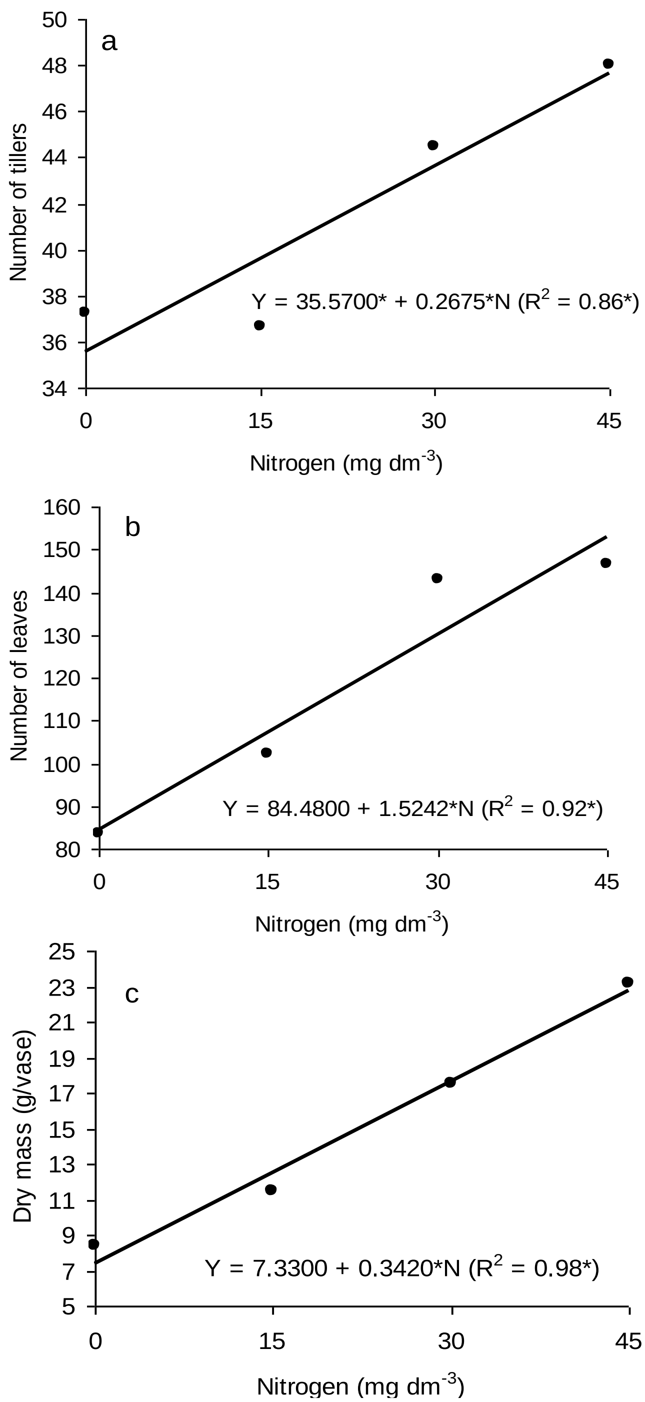


**Figure 1.** Production of tillers (a), leaves (b) and dry mass of shoots (c) in the second growth of ruzi grass a function of nitrogen rates.

30% increase in the number of leaves (Table 2). However, for the number of leaves in the second growth of the grass, no interaction was observed between the N rates applied at planting and those as topdressing (Table 2). The number of leaves in the second growth responded linearly to the N topdressing rates and increased up to 80% as the N topdressing rates increased (Figure 1b).

This increase in the number of leaves as a function of the N concentration is related, according to Silveira et al. (2010), to the genetic characteristics of ruzi grass, because the number of leaves is genetically determined and is conditioned by environmental variation, with the most pronounced effects being related to temperature and N rate. It can therefore be inferred that the plants receiving N will reach their maximum number of leaves/tillers sooner than those that are not fertilized (Paiva et al., 2012).

## Shoot dry matter production of ruzi grass

The shoot dry matter production in the first growth showed differences according to the N supply at planting. A supply of 15 mg $dm^{-3}$ N at planting promoted a 30% increase in the shoot dry matter production, which may have been influenced by the greater number of leaves per pot, because there was no change in the number of tillers (Table 1).

The increase in the shoot dry matter production of the ruzi grass in the first growth can be because the first response of pastures to N fertilizer application is a rapid uptake of N and increased plant growth (Sun et al., 2008). Thus, the observed result in this work should be taken into account in soybean succession with consortium of second-crop corn with ruzi grass because showed that N from biological fixation of the soybean can be insufficient for adequate grass production (Sousa Nunes et al., 2011).

In the second growth of the ruzi grass, the shoot dry matter production showed no interaction between the N fertilizers applied at planting and the rates as topdressing (Table 3). However, differences were observed between the absence of N fertilization and the application of 15 mg $dm^{-3}$ at planting (Table 3). This result also coincides with the increase in number of tillers and leaves per pot, which contributed to the production of the forage mass.

During the second growth, a linear response of the N topdressing supply was observed (Figure 1c), with a 310% increase between the lowest and the highest N doses used for the topdressing. The response to the N rates observed during the second growth reaffirms the need to adjust the N rate and the application period to coincide with peak absorption by the grass and the improvement possible from use of the residual N from the previous crops (Islam and Garcia, 2012).

The linear increase in the shoot dry matter production in the second growth of the ruzi grass, as function of the N rates , can be explained by the fact that tropical forage needs N in large quantities as a result of the deposition of most of this nutrient during cell division. Furthermore, it is known that N fertilizer increases the production of dry mass because it accelerates the N flow to the tissues,

**Table 3.** Production of dry mass of shoots and leaf/stem ratio of ruzi grass as a function of nitrogen applied at planting and topdressing (second growth).

| N at coverage (mg dm$^{-3}$) | Dry mass | | | Leaf/Stem | | |
|---|---|---|---|---|---|---|
| | N at planting (mg dm$^{-3}$) | | | N at planting(mg dm$^{-3}$) | | |
| | 0 | 15 | Means | 0 | 15 | Means |
| 0 | 7.68 | 8.43 | 8.06 | 0.97 | 1.05 | 1.01 |
| 15 | 11.15 | 11.70 | 11.46 | 1.11 | 1.10 | 1.11 |
| 30 | 16.66 | 18.36 | 17.51 | 1.10 | 1.07 | 1.08 |
| 45 | 22.50 | 23.75 | 23.13 | 1.09 | 1.04 | 1.07 |
| Means | 14.50$^{B}$ | 15.56$^{A}$ | | 1.07 | 1.07 | |
| F test | | | | | | |
| Linear effect | | | ** | | | $^{ns}$ |
| Quadractic effect | | | $^{ns}$ | | | $^{ns}$ |
| CV (%) | 8.77 | | | | 10.09 | |

Means followed by different capital letters for each variable differ by the F test ($P \leq 0.05$). **, $P \leq (0.01)$. $^{ns}$, not significant ($P \geq 0.05$).

increases the length of the leaves and increases the emergence and development of tillers. These factors are all positively correlated with forage production (Freitas et al., 2012).

The highest shoot dry matter production was observed in the final grass growth period, a result that may be related to the greater accumulation of non-structural carbohydrates that are mobilized from the roots and bases of the stems and transported to the shoots during the regrowth of the grass after the first cutting and to an increase in the number of tillers and leaves (Gomide, 1973; Botrel et al., 1990).

### Leaf/stem ratio of ruzi grass

The leaf/stem ratio in the first growth of the ruzi grass did not exhibit differences between the absence of fertilization and the application of 15 mg dm$^{-3}$ of N at planting (Table 1). The lack of differences in leaf/stem ratio is caused by acceleration in the growth rate with response in terms of forage accumulation, characterized by the proportional increase of leaves and stems in the forage mass (Pereira et al., 2010)

For the second growth, the F test revealed no interaction between the N rates applied at planting and those as topdressing. Although no significance at N rates, there was 1.9-fold reduction in the relationship for the N rates applied at planting with the growth second. Additionally, the leaf/stem ratio in the second growth, of 1:1, is considered critical. These results demonstrate that nitrogen applications should be systematically evaluated (Sun et al., 2008).

## Conclusions

The N rate of 15 mg dm$^{-3}$ applied at planting the ruzi grass promoted an increase in the numbers of leaves and shoot dry matter production in the first and second growths. During the second growth, N doses (15, 30 and 45 mg dm$^{-3}$) applied as topdressing increased the number of leaves and the shoot dry matter production. The available N from the previous crop (soybean) was sufficient for the initial tillering of the ruzi grass, but the number of tillers in the second growth indicated that when N is deficient, the development of tillers is inhibited.

This study showed that the correct management of N fertilization is necessary for ruzi grass when grown after a previous crop (soybean in this case).

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# Smallholder adoption of soil and water conservation techniques in Ghana

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**At the onset of climate change, the adoption of soil and water conservation (SWC) techniques in Africa sub of the Sahara has become even more crucial. The study aimed at estimating the determinants and effects of SWC adoption. The data was obtained from the Ghana Agriculture Production Survey (GAPS), a national level survey conducted by Ghana's Ministry of Food and Agriculture with technical and financial support from the International Food Policy Research Institute (IFPRI). A total sample size of 1,530 farm households selected from 20 districts across Ghana was used. The Poisson model was employed to estimate the determinants of adoption of SWC technology while the stochastic frontier model was used to analyze the effects of SWC technology adoption on technical efficiency. The study found that SWC adoption significantly affected technical efficiency in maize production. Significant policy variables that were found to positively influence the adoption of SWC techniques included credit, farm size, group membership and proximity to input sale points. Also, credit, education and extension services significantly influenced farmers' technical efficiency. There is the need for a holist approach to supporting farmers. In general, access to education, extension services and credit must be stepped up. Farmers must also be supported to form farm groups as a viable source of farm labour.**

**Key words:** Adoption, poisson model, technical efficiency, soil and water conservation.

## INTRODUCTION

Sustainable land management is the first pillar of the Comprehensive Africa agriculture program (CAADP), yet as reported by Marenya et al. (2012), adoption of improved land management practices remains low. For example, average application of fertilizer in sub-Saharan Africa (SSA) is only about 10 kg of nutrients/ha, which is the lowest level in the world (FAOSTAT, 2009). In Ghana, both governmental and non-governmental organizations have introduced a number of soil and water conservation (SWC) techniques, but the adoption rates are not better than what prevails elsewhere in the continent. Mindful of the fact that, most agricultural growth in the country has been attributed to land area expansion as opposed to yield increases (MOFA, 2007) improving factor productivity through dissemination of yields-enhancing technology has become a focus for Ghana's Ministry of Food and Agriculture. It is in this light that a study to estimate the determinants and effects of SWC techniques is most relevant. Even though research on the determinants of SWC techniques in other parts of the country abound (Nkegbe et al., 2011), this study which looks at the broader national picture, would provide empirical feedback to research and policy regarding rates of adoption of SWC and how such adoption affects farm yields and factor productivity.

Cereal production is a major component of small-scale farming in Africa. Among the cereals, maize is the most important as it forms the major staple for most communities (Djokoto, 2011). It is the largest staple crop and contributes significantly to consumer diets. It is

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also the number one crop in terms of area planted, accounting for between 50 to 60% of total cereal production in the continent. Though, the major producing areas are the forest and transitional zones of Ghana, it is grown in all parts of the country and maintains its role in agriculture sector and food security Millennium development accounts (MiDA, 2012). By investigating the adoption and productivity effects of SWC technology in Ghana, this paper contributes immensely in terms of providing feedback for research and policy.

Soil conservation practices involve managing soil erosion and its counterpart process of sedimentation, reducing its negative impacts and exploiting the new opportunities it creates (Noordwijk and Verbist, 2000). The common types of soil conservation technologies practiced in Ghana and considered in this study include mulching, crop rotation, row planting, water harvesting, fertilizer use, zero tillage, composting and agrochemical use

## LITERATURE REVIEW

The extent of use of a new technology or innovation is known as adoption while diffusion is the dispersal of technology in a community. Several disciplines have looked at adoption and diffusion from their own perspectives. Sociologists explained adoption and diffusion in terms of the nature of communication channels and differences in social positions, while Economists explained adoption and diffusion in terms of profitability. Anthropologists and geographers also explained adoption and diffusion as the compatibility of innovation and information flow respectively (Boahene, 1995).

According to Feder et al. (1985) rural sociologists were the first to undertake adoption and diffusion studies. These sociological studies, especially those by Ryan and Gross (1943) and Rogers (1962), provide the basis for economic studies. Rogers (1962), like others found that, diffusion was an S-shape function of time. This was interpreted to mean that, when a technology is first released, only few people adopt it. More people adopt it later thereby increasing the rate of adoption. The number of new adopters however decreases with time resulting in a decrease in the rate of adoption. Thus, the rate of adoption in a community increases initially and finally decreases.

Other studies that offer good economic approach to the study of diffusion and adoption of technology include Griliches (1957), Rogers (1962) and Feder et al. (1985). Griliches (1957) deals with the variation in parameters across districts using market size, corn acreage per farm and differences in profitability in the districts. Feder et al. (1985) found that, adoption decisions are influenced by farm size, risk and uncertainty, human capital, labour availability, credit constraints, land ownership and rental arrangements. Recent studies include that of Boyd et al. (2000) which dealt extensively on SWC practices in Sub-Sahara Africa (SSA) using Tanzania and Uganda as case studies.

In this study, the analysis was extended to include livelihood approaches to SWC, issues that have to do with farming systems, access to assets, transformation of structures and processes, institutions and policies. Bayard et al. (2006) studied the adoption and management of soil conservation practices in Haiti. In this study, they identified and analyzed factors influencing farmers' decisions to adopt rock walls. They also examined the factors which played a significant role in the management of land improvement technology. In their findings, it was discovered that age, education, group membership, and per capita income negatively influenced the ability to manage the rock walls, while age squared and the interaction between age and per capita income positively influenced the management. They asserted that, factors influencing management of rock walls may be different for each farmer or group of farmers depending upon the constraints they faced. Another study (Onweremadu et al., 2007) which dwelled on adoption levels revealed that, arable farming was dominated by relatively young and educated people who can enhance adoption and soil management technological transfer. The results in this study also indicated that, farmers were exposed to a wide range of impersonal sources of soil information and had potentials of disseminating such soil information to neighboring farmers. The study in question also found out that age, education, and income dictate the adoption status in the study area. .

In Ghana, Donkoh and Awuni (2011) did a similar work but their study was based only in the North, besides the study focused only on the determinants, but not the effects of adoption. Studies which proceeded to assess the impact of SWC techniques include Kato et al. (2009), Olarinde et al. (2012), and Kassa et al. (2013). However, the main limitation of Kassa et al. (2013) is that, it investigated farmers' perceptions about the impact of SWC techniques. Much as the perceptions of farmers with respect to the efficiency of SWC techniques are important, the approach is limited as farmers' perceptions may not be right or accurate. A methodology to measure the effects of SWC techniques in quantitative terms is more preferable. In this case, the studies by Kato et al. (2009) and Olarinde et al. (2012) were expedient. However, they estimated an average response model, and in the case of the latter, also used the propensity score matching. Estimation of technical efficiency is superior to these methods as it does not only give us the opportunity to measure the efficiency of individual farmers against the average but we are able to also know the determinants of such efficiency levels. This allows for a more pragmatic policy formulation.

The present paper contributes to the technology adoption literature with the examination of the factors influencing farmers' decision to adopt SWC techniques and the effects on their technical efficiency, from the perspective of a developing country.

## METHODOLOGY

The study employed two main methods in analyzing the determinants of adoption and technical efficiency effects of SWC technology adoption. The first involved the estimation of a poisson model to determine the factors that influence the adoption of SWC techniques. As indicated earlier, many adoption studies involves the estimation of probit or logit model, usually in instances where only one technique (or single attribute dependent variable) is involved. In the case of this study, a number of SWC techniques are involved. We therefore employed the poisson model, which allows us to estimate more than one SWC as a function of farmer and farm covariates. The second approach uses the stochastic frontier model, to analsye the technical efficiency effects of SWC technology adoption.

### The Poisson regression model

According to Greene (1997), the Poisson regression is represented by the basic Equation:

$$\Pr(Y = y) = \frac{e^{-\lambda}\lambda^{y}}{y!}, \qquad y = 0, 1, 2 \ldots\ldots\ldots$$

The parameter $\lambda$ is assumed to be log-linearly related to regressors $x_i$. Therefore,

$$\ln(\lambda) = \beta^{'} x_i \tag{1}$$

The log-likelihood function is given by the Equation:

$$lnL = \sum_{i=1,2,\ldots\ldots n} [-\lambda_i + y_i \beta^{'} x_i - ln y_i!] \tag{2}$$

The expected number of SWC practices per farm is given by the Equation:

$$E[y_i|x_i] = Var[y_i|x_i] = \exp\left(x_i \beta^{'} + \mu_1\right) \tag{3}$$

where, β is a 1 × k vector of parameters; × is a k × 1 vector with the values of k independent variables in the $i^{th}$ observation and n is the number of observations.

The equation can also be expressed as:

$$E[Y_i] = exp^{(\beta_1 x_{1i})} exp^{(\beta_2 x_{2i})} \ldots \ldots exp^{(\beta_k x_{ki})} \tag{4}$$

$$= \exp\left(\beta_j X_{jn}\right) C_i \qquad (i = 1, 2 \ldots\ldots\ldots\ldots\ldots\ldots n)$$

where, j can take any value from 1 to k and identifies a specific explanatory variable and Ci is a constant representing the product of the remaining exponential terms in Equation (4). For dichotomous explanatory variables, if $x_{ji} = 0, E(Y_i) = C_i$, and when $x_{ji} = 1, E(Y_i) = \beta_j C_i$,

Therefore, $100 \times (exp^{\beta_j} - 1)$ calculates the percentage change on E(Y) when $x_j$ goes from zero to one, for all observations (i). In general, for independent variables that take several integer values, the percentage change in the expected level of adoption when $x_j$ goes from $x_{j1}$ to $x_{j2}$ can be calculated as:

$$100 \times \frac{exp^{\beta_j x_{j2}} - exp^{\beta_j x_{j1}}}{exp^{\beta_j x_{j1}}} \tag{5}$$

Based on the conceptual framework, the empirical model is estimated using the farmers' characteristics plausibly assumed to influence their adoption decisions. The covariates include farm and farmer characteristics such as gender, age, age squared, education, farm size, household size, group membership, number of extension visits, credit obtained by the farmer and distance to market/input store. The empirical model for adoption is specified below:

$$Logy_i = (\beta_0 + \beta_1 Gender + \beta_2 Age + \beta_3 Age^2 + \beta_4 Edu + \beta_5 FSize + \beta_6 HHsize + \beta_7 Group\_mem + \beta_8 Ext\_Visits + \beta_9 Credit + \beta_{10} Input\_dist + \varepsilon_1)$$

Where; y = 0 if a farmer failed to adopt any of the eight farming practices during the farming season under review; y = 1 if a farmer adopted any one; y = 2 if a farmer adopted any two; y = 3 if a farmer adopted any three; y = 4 if a farmer adopted any four; y = 5 if a farmer adopted any five; y = 6 if a farmer adopted any six; y = 7 if a farmer adopted any seven; and y = 8 if a farmer adopted all the eight.

### The stochastic frontier model

The stochastic frontier production function assumes the presence of technical inefficiency of production through which the determinants of technical efficiency are drawn. Hence, the function is defined as:

$$Y_i = f(X_i;\, \alpha_i) + \varepsilon \tag{6}$$

for *i* = 1, 2, 3…… ………………n

Whereby $Y_i$ is the output of farmer *i*, $X_i$ are the input variables, $\alpha_i$ are production coefficients and ε is the error term that is composed of two elements, that is:

$$\varepsilon = v_i - u_i \tag{7}$$

Where $v_i$ is the stochastic error which is assumed to be identically, independently and normally distributed with zero mean and a constant variance ($\sigma_v^2$). The other second component ($u_i$) is a one-sided error term which is independent of $v_i$ and is normally distributed with zero mean and a constant variance ($\sigma_u^2$), allowing the actual production to fall below the frontier but without attributing all short falls in output from the frontier as inefficiency.

Technical efficiency is associated with the ability to produce on the frontier isoquant (Farrell, 1957). In other words, it is the ratio of the observed output to the corresponding frontier output, conditioned on the level of inputs used by the farm. Inefficiency on the other hand is producing below the frontier isoquant. Jondrow et al., (1982) stated that technical efficiency estimation is given by the mean of the conditional distribution of inefficiency term $u_i$ given ε; and thus is defined by:

**Table 1.** Summary definition of variables.

| Variable | Definition/measurement | Mean | Standard deviation |
|---|---|---|---|
| Revenue | Amount in Ghana Cedis | 344.76 | 738.24 |
| Gender | Dummy (male = 1; female = 0) | 0.75 | 0.43 |
| Age | Number of years | 50.56 | 15.86 |
| Education | Years spent in formal schooling | 3.78 | 5.08 |
| Farm Size | In acres | 5.05 | 7.05 |
| Household Size | Number of people | 6.20 | 4.13 |
| Number of extension visits | Number of visits made to extension services and by extension agents (per year) | 0.00 | 0.00 |
| Group Membership | Dummy (1 if the farmer is a member of a group and 0 otherwise) | 0.41 | 0.49 |
| SWC | Total number of SWC techniques adopted by a maize farmer | 1.09 | 1.30 |
| Fertilizer | Amount in Ghana Cedis | 11.75 | 25.44 |
| Labour | Amount in Ghana Cedis | 2.60 | 6.66 |
| Distance/proximity to input store | In kilometers | 0.91 | 3.93 |
| Credit | Amount in Ghana Cedis | 16.76 | 319.39 |

Source: Result from data analysis (2012).

$$\mathrm{E}(u|\varepsilon_i) = \frac{\sigma_u - \sigma_v}{\sigma} - \left[\frac{f(\varepsilon_j\lambda|\sigma)}{1 - F(\varepsilon_i\lambda|\sigma)} - \frac{\varepsilon_i\lambda}{\sigma}\right] \tag{8}$$

here $\lambda = \sigma_u/\sigma_v$ , $\sigma^2 = \sigma_u^2 + \sigma_v^2$ while $f$ and $F$ stand for the standard normal density and cumulative distribution function, respectively evaluated at $\varepsilon_i\lambda/\sigma$. We define the farm–specific technical efficiency in terms of observed output ($Y_i$) to the corresponding frontier output ($Y_i$*) using the existing technology derived from the equation above as:

$$\mathrm{TE}_i = \frac{Y_i}{Y_i^*} = \frac{E(Y_i|u_i, X_i)}{E(Y_i|u_i = 0, X_i)} = e^{-[E(u_i|\varepsilon_i)]} \tag{9}$$

The values of TE range between 0 and 1 where the latter shows that the farm is fully efficient.

### Data

The data used for this paper is from a cross-sectional baseline survey known as the Agriculture Production Survey (GAPS). The GAPS was conducted by Ghana's Ministry of Food and Agriculture with technical and financial support from the Ghana Strategy Support Program (GSSP) of the International Food Policy Research Institute (IFPRI). The data represents the first phase of the survey piloted in twenty districts across the country during the 2011/2012 cropping season. This paper uses a sample 1,530 which was collected from 800 enumeration areas located in 20 districts across the then regions of Ghana.

## RESULTS

This section presents the results of the estimation of Poisson and frontier models. Table 1 presents the definition and measurement of key variables contained in the analysis as well as the descriptive statistics of the variables used in the study.

The mean of the total value of output was found to be GH¢ 344.00 per acre. This was achieved by utilizing on average, 5 acres of land, GH¢ 3.00 of labour, GH¢ 12.00 of fertilizer and the adoption or otherwise of SWC . The average age of the farmers was 51 years. The level of education among maize farmers was low, considering the mean schooling years of 4. The mean household size was 6. About 41% of the farmers participated in group activities while 59% did not take part in any group activities. The average distance from the farm to the market/input store was 1 km and the average credit obtained per farmer was GH¢ 17.00.

### Factors influencing the adoption of SWC techniques in Ghana

One objective of this paper was to identify and analyse the factors that influenced the adoption of SWC techniques in the 2011/2012 farming season in Ghana. The dependent variable is a vector of SWC techniques including mulching, composting, crop rotation, water harvesting, fertilizer use, agrochemical use, zero tillage and row planting. This composite vector of SWC techniques is used in a Poisson estimation procedure to determine the farmer and farm characteristics that influence the adoption or otherwise of these techniques. The estimation results of the Poisson model are presented in Table 2. Note that, the dependent variable of the model (No. SWC) is observed and not latent, therefore the coefficients of the variables are useful, in that they measure the direct effects of the

**Table 2.** Maximum likelihood estimation of the determinants of SWC technology adoption.

| Variable | Coefficient | Standard error | Z |
|---|---|---|---|
| Gender | 0.4402 | 0.0685 | 6.43*** |
| Age | 0.0049 | 0.0087 | 0.56 |
| Age squared | -0.0001 | 0.0001 | -0.72 |
| Education | -0.0472 | 0.0056 | -8.42*** |
| Farm size | 0.0103 | 0.0027 | 3.85*** |
| Household size | 0.0338 | 0.0053 | 6.42*** |
| Group membership | 0.3916 | 0.1387 | 2.82*** |
| Extension visits | -1.2113 | 0.6432 | -1.88* |
| Credit | 0.0001 | 0.0000 | 2.58** |
| Distance | -0.0573 | 0.0117 | -4.88*** |
| Constant | -0.4495 | 0.2291 | -1.96** |

*, ** and *** are levels of significance at 10, 5, and 1%, respectively, number of observations 1506, LR $X^2$ (10), 291.67, Prob >$X^2$, 0.0000***, Pseudo $R^2$ 0.0634, Log likelihood-2153.3927. Source: Result from data analysis (2012).

explanatory variables on the dependent variable. The factors influencing farmers' adoption of SWC included gender, age, age squared, farm size, household size, years of education, cooperative participation, number of extension visits, total credit and distance to selling point/market.

Many of the right hand side covariates were significant and exhibited patterns consistent with our *a priori* expectations. The goodness of fit parameters of the model indicated that, the model adequately predicted the determinants of the adoption of SWC technology. The chi-squared value was significant at 1%, implying that all the variables jointly determine the dependent variable. Household characteristics such as gender, household size and years of education were found to be significant at 1% level of significance.

Gender and household size were positively related to the number of technologies adopted while years of education of the farmers was found to have negative influence on the number of techniques adopted. This means that male farmers tended to adopt more of the techniques than their female counterparts. Also, farmers with larger household size tended to adopt the techniques more than those with smaller household size. This is consistent with our *a priori* expectation because the adoption of SWC techniques is laborious and needs more hands. The negative sign of the education variable means that those with no education or lower educational background tended to adopt the techniques more than those with higher level of education. This goes contrary to many studies (Abbey and Admassie, 2004; Doss and Morris, 2001; Foltz, 2001) that argue that, farmers who have better education and are able to read and understand information about the technology tend to have greater probability of adoption than their illiterate counterparts. Farm size was also found to be significant at 1% level of significance and maintained the expected positive sign. This is to say that, farmers with larger farm size adopted more technologies than their counterparts. This is however, consistent with our *a priori* expectation and confirmed that of other studies, especially Donkoh and Awuni (2011).

Group membership was also found to be significant at 1% level of significance and had a positive influence on adoption implying that farmers who belong to a farmer group had greater probability of adoption than those who did not. However, while the extension variable was significant at 10% level of significance, it showed a negative influence on adoption, hence inconsistent with the findings of Donkoh and Awuni (2011). Similarly, the fact that, credit was significant and maintained its expected positive sign implies that credit is an important source of capital which facilitated SWC technique adoption in the cropping season. This is consistent with Foltz's (2001) hypothesis that, farmers who have better access to credit stand a better chance of adopting technology faster than those who are capital-constrained. Ekboir et al. (2002) and Simtowe and Zeller (2006) had similar findings.

The closer an input store was to the farmer's field, the greater the adoption of SWC techniques. Proximity to an input store is not only an incentive for farmers to buy the inputs, but it reduces the cost of transporting the input to the farmer's house.

## Effect of SWC technique adoption on output of maize farmers in Ghana

The parameters and related statistical results obtained from the stochastic frontier production function analysis are presented in Table 3. The study revealed a significant effect of SWC technique adoption on maize output. This is consistent with the findings of Olarinde et al. (2012) and Kato et al. (2009). In addition to the SWC variable, all

**Table 3.** Maximum likelihood estimation of the stochastic frontier model for maize farmers in Ghana.

| Variable | Coefficients | Standard error | Z |
|---|---|---|---|
| **Output function** | | | |
| Constant | 7.0039 | 0.0927 | 75.11*** |
| Farm size | 0.1041 | 0.0515 | 2.02** |
| Labour | 0.1129 | 0.0519 | 2.18** |
| Fertilizer | -0.1039 | 0.0346 | -3.0*** |
| Number of SWC adopted | 0.19440 | 0.03755 | 5.18*** |
| **Inefficiency model** | | | |
| Constant | 2.7113 | 0.3530 | 7.68 |
| Gender | 0.3697 | 0.0888 | 4.16*** |
| Age | -0.0084 | 0.0136 | -0.62 |
| Age squared | 0.0001 | 0.0001 | 1.05 |
| Education | -0.0271 | 0.0069 | -3.91*** |
| Farm size | -0.0050 | 0.0063 | -0.80 |
| Household size | 0.0437 | 0.0099 | 4.39*** |
| Group membership | 0.3723 | 0.2438 | 1.53 |
| Number of extension visits | -0.0619 | 0.0101 | -6.08*** |
| Credit | -0.0004 | 0.0002 | -2.31** |
| Distance | -0.3898 | 0.0864 | -4.51*** |
| Sigma square | 17.7146 | 1.6702 | |
| Gamma (γ) | 0.9763 | 0.0038 | |
| Sigma square ($\sigma_u^2$) | 17.2942 | 1.6672 | |
| Sigma square ($\sigma_v^2$) | 0.4204 | 0.0568 | |
| Mean technical efficiency | 0.5011 | | |
| Loglikelihood function | -3928.0657 | | |

*, ** and *** are levels of significance at 10, 5, and 1% respectively. Source: Result from data analysis (2012).

the conventional inputs were significant and maintained their expected sign, except fertilizer input, which although was significant had a negative sign, implying that, the greater its application the less the output. Kumornu et al. (2013) also found a negative sign for fertilizer in the Eastern region of Ghana. Also, in general, maize farmers in Ghana is averagely efficient as the estimated mean technical efficiency was found to be 0.50 ranging between 0.35 and 0.83. Thus, there is room to increase output without increasing input amounts at the present level of technology by 50%.

In the inefficiency effects model, the variables that significantly influenced farmers' technical efficiency were gender, education, household size, extension visits, credit and distance to the market. The negative sign of the gender variable implies that, female farmers were more technically efficient than their male counterparts. This is in contrast with that of Donkoh (2011) who found that, male headed households were more efficient. Also, in this present study, technical efficiency was greater for farmers with many years of formal education, farmers who received extension visits as well as famers who had access to credit. These findings are consistent with that of many studies (Seidu, 2008; Binam et al., 2008; Kumornu et al., 2013). The negative sign of the distance variable, however, also implies that, farmers who stayed farther away from the market were more technically efficient.

## DISCUSSION

Even though the negative significance of the education variable did not meet our *a priori* expectations, the finding is quite plausible as a result of two reasons. First the adoption of SWC techniques does not require much formal education compared with some modern technologies. SWC techniques are indigenous techniques which have been with the farmers since time immemorial; hence they do not need formal education to understand its adoption. Perhaps this also explains why the extension variable did not meet our *a priori* expectation.

Second, the adoption of SWC techniques is quite laborious and time consuming, which means that it is unattractive to the educated since they are normally busy with other non-farm activities. The labourous nature of the adoption of SWC techniques and its consequent need for a large labour force is evidenced by the significance and positive sign of the household size and group membership variables. In Africa, the household and farmer groups are a significant source of farm labour. In the case of household labour, even children have their role to play in the farming business, especially when it comes to activities such as mulching and water harvesting. Against the backdrop of limited money to hire labour, farmers put themselves into group to work for one another for reciprocal gains.

The importance of agricultural credit in peasant farming cannot be over-emphasized. This is also evidenced by the positive significant coefficient of the credit variable. With credit, farmers can access the tradable SWC techniques such as inorganic fertilizers and insecticides. Credit is not the only factor that facilitates the adoption of tradable SWC techniques; proximity to input stores where these techniques are sold is important. Already, some of these inputs are expensive to farmers and they would not like to incur extra costs by way of transportation, to cart the inputs to their houses or farms.

A closer examination of the results of the adoption and efficiency models reveals some contradictions in the way that the explanatory variables influenced the dependent variables. For instance, while the probability of adoption was greater for households that were closer to the input stores, these households were less efficient than their counterparts who were farther away. However this is not unsurprising, technical efficiency is more than just the adoption of SWC. To be efficient in one's farming work, one needs to have an undivided attention. Other things being equal, farming in the rural or peri-urban is more effective than farming in the urban centers (proximity to inputs stores implies living in a relatively urban area). Farmers in the urban centers normally tend to have a divided attention, which goes a long way to adversely affect their farming work. Besides, MoFA (2007) recognized that, the problem of input demand in Ghana goes beyond proximity of input stores to farmers, there is the need, beyond the establishment of input stores in the districts, for the passage and enforcement of laws and regulations as well as foster an enabling environment to enhance trade in and use of input.

Also, even though education and extension services influenced adoption negatively, they maintained a positive correlation with technical efficiency. While the adoption of SWC techniques may not have required education and extension services because the farmers were familiar with the techniques, there might be other areas that they (education and extension services) were needed to enhance farmers' technical efficiency.

Furthermore, even though male farmers had greater adoption, they were less efficient than their female counterparts. The argument in the literature is that women are normally marginalized in terms of access to complementary inputs that facilitate technology adoption. This could explain their relatively low probability of adoption. This notwithstanding, they were more technically efficient. The point has always been raised in favour of women that affirmative action must be taken to bring them up to the level of their male counterparts in terms of access to socioeconomic benefits. Lastly, while the probability of adoption was greater for larger households, smaller households were more technically efficient. The danger in the use of large families on small plots is the likelihood of negative marginal returns, which translates into technical inefficiency.

The implication of these seemingly contradictory findings on policy formulation is to take a holistic approach, so that both adoption and technical efficiency are increased. However, it should be noted that, in principle, technology adoption is not an end in itself but a means to raising the efficiency of farmers. This means that, in dealing with variables that exert contracting influence on technology adoption and efficiency, priority should be given to technical efficiency. This implies, from our findings, that besides credit, access to education and extension visits should be promoted. Similarly, group membership should be encouraged since it facilitated adoption, without leaving any negative impacts on efficiency.

Ownership of large farms should also be encouraged since it did not only increase adoption but increased output (in the first part of the stochastic frontier model). This should however, not be done at the expense of small-scale farmers, considering the fact that, they constitute over 90% of the farming population (Seini, 2002). The usual way is to encourage the formation of the out grower schemes where large farmers are strengthened to form nuclei to also strengthen smaller farms.

## Conclusion

The objectives of this study were to investigate the factors that influenced the adoption of SWC techniques and to determine the effects of adoption on maize output in Ghana. While the first objective was achieved by estimating a Poisson model the stochastic frontier model was estimated to meet the second objective. Significant policy variables that were found to positively influence the adoption of SWC techniques were credit, farm size, group membership and proximity to an input store. Also, adoption, credit, education and extension services significantly influenced farmers' technical efficiency. We propose a holistic approach in formulating policies to increase adoption and efficiency, while giving priority to technical efficiency.

The strength in this study lies in the opportunity to estimate the adoption behavior of farmers when multiple techniques are involved and see how policy variables influence adoption and technical efficiency at the same time. We have proposed that, where a variable exerts contrasting effects on adoption and output/technical efficiency, the latter should be given priority since the former is only a means to achieve the latter. The limitation of the study lies in the fact that, we could not apply Heckman's two stage model to correct for selectivity (which is applicable in the case of the probit/logit model) and incorporate a welfare model so as to see the (net) effect of technology adoption on the living standards of farmers. Our data does not include welfare variables to make this possible. We hope that future studies would overcome these limitations.

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**Abbreviations:** **CAADP,** Comprehensive Africa agriculture program; **CSOs,** civil society organizations; **FBOs,** farmer base organizations; **GAPS,** Ghana agriculture production survey; **GSSP,** Ghana strategy support program; **IFPRI,** international food policy research institute; **MDGs,** millennium development goals; **MiDA,** millennium development accounts; **METASIP,** medium term agricultural sector investment program; **SWC,** soil and water conservation; **SSA,** sub-Sahara Africa.

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*Short Communication*

# Effects of different pre-sowing seed treatments on germination of *Tectona grandis* species

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***Tectona grandis* (teak) is an economically important tree. It is a valuable tree whose wood is used in both shipping and carpentry industries. In this work we evaluated 11 treatments to assess the percentage of seed germination of *T. grandis*. The results showed that after 21 days, four treatments had greater germination percent when compared with the control. These treatments were, (i) when the seeds were exposed to sunlight for three days, 78% germination was observed (ii) the seeds were soaked in water for 72 h, 66% germination was observed (iii) the seeds were soaked in water for 12 h and dried for 12 h at a temperature range of between 22 and 45°C, 79% germination was observed, (iv) finally, the seeds were soaked in fast-flowing water for 24 h and exposed to sunlight for 24 h, 80% germination was observed. In this study we found that the best technique to stimulate germination is to soak the seeds for 24 h, and exposed them to sunlight for 24 h. In conclusion, the technique is easy to apply and also we can treat many seeds at the same time.**

**Key words:** *Tectona grandis,* germination, seeds.

## INTRODUCTION

*Tectona grandis* L. f., commonly known as teak, is a deciduous tree, native of Southeast Asia, where it grows up to 45 m high (Weaver, 1993). Teak tolerates a lot of climates, but grows best in moist tropical climates with a pronounced dry season (3-6 months) (Kaosa-ard, 1981). Plantations in Africa and Latin America, where they have been introduced as an exotic species from early last century (Foster et *a*l., 1995; Kjaer and Foster, 1996; Francis, 2003; Araya et al., 2005). They are from a great commercial value because of certain features of the wood such as; strength, durability and stability. Therefore, it is widely used in shipbuilding, fine furniture, decorative objects, poles and fuel. Although, Mexico has a large forest area about 64 million, the deforestation rate is as high as 2% in the jungles and 1.5% in temperate forests (Torres, 2004), reducing the country's forest area. Deforestation is promoted by population growth, poverty and marginalization index is manifested by opening practice areas for agriculture, grazing and urbanization (Velázquez et al., 2002). Forest plantations can help to reduce the pressure on natural forests (Evans, 2009), for that reason the increase in the area of forest plantations in developing countries is important. According to the Comision Nacional Forestal (CONAFOR, 2011a) in Mexico, it has supported the establishment of 202,163.24 for commercial plantations, in order to reduce the

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dependence on imports. Exotic tree specie that has recently gained attention in Mexico is *Tectona grandis* Linn. F., which has been tested as intensive forest cultivation in the states of Campeche, Chiapas, Michoacan, Tabasco, Nayarit and Veracruz (CONAFOR, 2011b)? The viability of teak seeds varies from 40 to 85% depending on certain factors such as; seed size, seed source, collection year, weather conditions during flowering and fruiting (Kaosa-Ard, 1981). Although, since 1976 the International Seed Testing Association has defined this protocol of teak germination, some of the problems faced by the forest seed certification program are the large differences in germination results between laboratories. The purpose of this research was to: break the seed dormancy of *T. grandis* using different treatments, describe the effects of treatments on the germination *T. grandis*, and finally to propose treatments that maximize seed germination of the specie.

## MATERIALS AND METHODS

### Seeds

The seeds used in the germination tests with different treatments were obtained from the Forest Seed Bank of the Tropical Agricultural Research and Higher Education Center (Centro Agronómico Tropical de Investigación y Enseñanza CATIE) CATIE lot 123/07F-06.

### Scarification of seeds

For each treatment, 30 seeds were used and the whole experiment was repeated four times. The seeds were subjected to different treatments: 1) they were exposed to sunlight for three days, 2) they were soaked in standing water for three days, 3) they were soaked in standing water for 12 h and subsequently they were exposed to sunlight 12 h repeating that procedure for 3 days, 4) they were soaked for 24 h in fast- flowing water and then exposed to sunlight 24 h, repeating this procedure for 3 days, 5) they were soaked in cold water (5°C) for 48 h, 6) they were soaked and then stored in cold (3°C) for 48 h, 7) they were exposed for 5 min to 100°C, 8) they were soaked in hot water to 95°C for 1 min, 9) they were soaked in sulfuric acid for 5 min, 10) it was accomplished the mechanical disruption of the testa, 11) Control.

### Germination experiment

The treated and untreated seeds were planted at 0.5 cm depth in a seed raising, locally purchased containing organic material mixture (peat moss). Each block of 30 planted seeds was placed at random in a greenhouse and they were watered daily.

### Standard germination test

The percentage of germination was determined on day 7, 14 and 21. Germination was assessed as the percentage of seeds producing normal seedlings as defined in the handbook of seedling classification (International Seed Testing Association, 1993). Parameters such as germination percentage (GPCT), Germination Index (GI) and Germination Rate Index (GRI) were calculated. All statistical analyses were done using SAS (SAS institute Inc., 2004).

$$GI = \frac{\sum (Nx)\,(DAS)}{\text{Total No. of seedings that emerged on the final count}}$$

$$GRI = \frac{\text{Germination index}}{\text{Germination percentage (0-1 scale)}}$$

Where, Nx is the number of seedling that emerge on day x after planting, DAS is day after planting.

$$GPCT = \frac{\text{Total No. of seedings that emerged on the final count}}{\text{Total No. of seeds planted}} \times 100$$

## RESULTS AND DISCUSSION

The seed exposure to sunlight for 3 days has an effect on the germination of 78%, (Table 1), while soaking in water for 3 days the result is 66% germination. In the treatments where the seeds were soaked in flowing water for 12 and 24 h and later exposed to sunlight for 12 and 24 h, the germination results are similar 79 and 80% according to Table 1, this difference in germination between seeds were soaked in flowing water and standing water may be due to the release and accumulation of compound that inhibited germination as reported by Milimo and Hellum (1987) and Willan (1990), seeds of *Lepidium sativum*, in this work could be that the same compounds are inhibiting the germination of *T. grandis*, in the outcome of treatment where is used flowing water, the compounds that release the *T. grandis* seeds would not be accumulating by themselves, whereby the germination percentage is higher, treatments of soaking the seeds in cold water and place them in cold, the results of the germination percentage were 56 and 59%, when we applied to the seeds dry heat the percentage of germination was 58% (Table 1) this result is very similar to low temperature treatments, treatment of soaking the seeds in hot water for one minute showed the lowest germination percentage (0%), as well as other treatments that showed a low percentage (19%) it was when the seeds were soaked with concentrated sulfuric acid for 5 min (Table 1) in some reports sulfuric acid usage increased germination, in this study occurred the opposite. A decrease in seed germination percentage called teak, as *Accacia angustissima* has reported in higher exposure times where sulfuric acid decreased germination (Rincón et al., 2003), while the mechanical treatment of the seed testa disruption was obtained in 60% germination. Moreover, treatment where seeds were soaked for 3 days has a slightly higher percentage (66%) compared to control. As we can observe the results of the treatments when they were applied at low temperatures, high temperatures, dry heat, sulfuric acid germination, percentages are lower than the control treatment (63%). However, the best

**Table 1.** Percentage of germination after 7, 14 and 21 days, Germination Index (GI) and Germination Rate Index (GRI) after 21 days for seeds of *Tectona grandis*.

| Treatment | Percentage of germination (days) | | | GI | GRI |
|---|---|---|---|---|---|
| | 7 | 14 | 21 | | |
| Sunlight 3 days | 50 | 70 | 78[a] | 37.9[a] | 49.7[b] |
| Soaked 3 days | 35 | 53 | 66[ab] | 36.5[ab] | 58.1[b] |
| Soaked 12 h + Sunlight 12 h | 40 | 64 | 79[a] | 35.9[a] | 45.6[b] |
| Soaked 24 h + Sunlight 24 h | 44 | 74 | 80[a] | 38.0[a] | 47.7[b] |
| Soaked in cold water 48 h | 22 | 38 | 56[b] | 33.1[abc] | 59.6[b] |
| Soaked and incubated in cold 48 h | 27 | 39 | 59[b] | 33.5[abc] | 58.2[b] |
| Dry heat for 5 min (100°C) | 22 | 34 | 58[b] | 33.6[abc] | 65.1[b] |
| Soaked at 90°C for 1 min | 0 | 1 | 1[c] | 0[d] | 0[b] |
| $H_2SO_4$ 98% for 5 min | 2 | 3 | 19[c] | 25.7[c] | 72.6[a] |
| Mechanical rupture of the testa | 37 | 59 | 60[b] | 38.9[a] | 66.5[b] |
| Control | 13 | 17 | 63[b] | 26.1[c] | 41.2[b] |

Means having different letters are significantly different at 5% level of significance.

results of seed germination of teak were treatments for exposure to sunlight for three days 78%, seeds soaked for 12 h and exposed to sunlight 12 h giving 79% germination results and the treatment that showed higher germination percentage (80%) was when the seeds were soaked in flowing water for 24 h and exposed to sun for 24 h. The results obtained in this study show that four of the treatments are at or above the germination percentage (Table 1) as reported by ISTA (1999) for *T. grandis* seeds. Thus, treatment outcomes presented higher germination percentage (80%), germination index (38) and coefficient of germination rate (47.7) (Table 1) is slightly lower than 85% CATIE reported by Chávez and Fonseca (1991). As seen in the results, both parameters show improvement in the speed of germination of teak seeds. Wherefore with bases at the results we can establish that four of the treatments used in this work to increase the percentage of germination of teak can be used in the process of germination of *T. grandis*, and that the process of these four treatments are easy to use and evaluate the germination percentage by seed producers and farmers.

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*Full Length Research Paper*

# Concentration of nitrogen, phosphorus and potassium in tropical grasses fertilised with wood ash in cerrado oxisol

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**Nitrogen, phosphorus and potassium are nutrients that are directly involved in the entire life cycle of plants. Wood ash is solid with high or low concentrations of phosphorus and potassium depending on the material of vegetable origin. The objective of the present study was to evaluate the concentrations of nitrogen, phosphorus and potassium in tropical grasses in 2 cultivars of *Brachiaria brizantha* resulting from differing doses of wood ash. Completely randomised design in a 6x2 factorial with 6 doses of vegetable ash (0; 3; 6, 9; 12 and 15 g dm$^{-3}$) and 2 cultivars of *B. brizantha* (Marandu and Xaraes) with 6 replications. In the first cut, the nitrogen concentration in the shoots of Marandu grass increased by 65.13%, and the potassium concentration increased by 36.12 and 42.37% in the Marandu and Xaraes grasses, respectively. In the third section, the phosphorus concentration in the shoots of both grasses increased 38.78%. In the roots of the Marandu and Xaraes grasses, the concentrations of phosphorus and potassium increase by 25.17 and 35.93%, respectively. The wood ash as fertiliser improves the concentrations of nitrogen, phosphorus and potassium in the shoots and roots of the tropical grasses Marandu and Xaraes.**

**Key words**: *Brachiaria Brizantha*, fertiliser alternative, solid waste.

## INTRODUCTION

The use of solid waste such as the ash plant in agriculture has enabled an alternative form of fertilisation and a way to replace nutrients in the soil, consequently affecting the crop. This residue contains varying concentrations of minerals (Mello, 1930) and, once in the soil, works as a corrective fertiliser (Ferreira et al., 2012), improving the soil fertility.

Soils under Cerrado have a naturally low fertility, and in this case, it may be feasible to use wood ash as a fertiliser. The ash improves the soil characteristics and can provide better crop growth as it meets the recommendations for crop need, fertiliser dose and soil class.

These aspects that relate to alternative forms of fertiliser are relevant for sustainable development, which aims to increase agricultural production and improve the

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nutritional quality of plants while offering another option to dispose of by products that are produced in large quantities.

Wood ash usually presents a relatively low percentage of nitrogen, as this element is lost by combustion (Rigau, 1960). In contrast, this residue generally contains moderate amounts of phosphorus (Osaki and Darolt, 1991) and high concentrations of potassium (Zimmermann and Frey, 2002; Feitosa et al., 2009).

In this context, to increase the productivity of pastures, it is essential to adopt a management system that meets the needs of the grass and that, if well-managed, will result in good production rates. One of the ways to increase crop productivity is by providing an adequate supply and replenishment of nutrients to the soil, allowing for the good production of forage with nutritional quality.

Thus, nitrogen is the main nutrient for the maintenance of the yield of forage grasses and for the formation of essential proteins, chloroplasts and other compounds that actively participate in the synthesis of organic compounds. Phosphorus is the nutrient most often cited as the main cause of the low productivity of pastures on acidic soils of low fertility and is considered the most important nutrient for cattle pastures.

However, as grasses require significant amounts of potassium, fertilisation is necessary so as not to limit the response to nitrogen. Thus, the objective of the present study was to evaluate the concentrations of nitrogen, phosphorus and potassium in the shoots and roots of the Marandu and Xaraes grasses in response to varying doses of wood ash.

## MATERIALS AND METHODS

The experiment was conducted in a greenhouse from August to December 2011. The average temperature during the experimental period was 34°C. The soil was an Oxisol that was collected in the 0 to 0.2 m layer in an area under Cerrado vegetation.

The chemical characteristics of the soil were as follows: pH in $CaCl_2$ = 4.0, MO = 24.8 g $dm^{-3}$, P-resin = 1.2 mg $dm^{-3}$, K = 40.0 mg $dm^{-3}$, Ca = 0.2 cmolc $dm^{-3}$, Mg = 0.1 cmolc $dm^{-3}$, Al = 1.3 cmolc $dm^{-3}$ and V = 6.5%. The particle size characteristics of the soil were as follows: sand = 476 g $kg^{-1}$, clay = 441 g $kg^{-1}$ and silt = 83 g $kg^{-1}$.

The wood ash that was used was from the boiler food industry, and its bioenergy were as follows: pH in $CaCl_2$ = 10.90, N = 0.56%, $P_2O_5$ (Neutral Ammonium Citrate + Water) = 1.7%, $K_2O$ = 2.72%, Zn = 0.01%, Cu = 0.01%, Mn (CNA + water) = 0.00, B = 0.02%, Ca = 2.7% and S = 1.49%.

The experimental design was completely randomised in a 6x2 factorial design with 6 doses of vegetal ash (0; 3; 6; 9; 12 and 15 g $dm^{-3}$) and 2 cultivars of *Brachiaria brizantha*, Marandu and Xaraes, with 6 replications. Each plot consisted of plastic pots with a 7-$dm^3$ soil capacity. The ash was incorporated into the plant soil and incubated for 30 days. Liming was not performed.

Irrigation was performed via the gravimetric method, and throughout the experimental period, the soil moisture was maintained at 60% of the maximum capacity of water retention. After the incubation, the grasses were sown at an approximate depth of 2.5 cm with 20 seeds per pot, and when the plants were 10 cm high, thinning was performed based on the criteria of size, uniformity and homogeneity, leaving five plants per pot.

All of the plots received nitrogen fertiliser equivalent to 200 mg $dm^{-3}$ using urea as a nitrogen source. This fertilisation was repeated with each cut and was performed during the first thinning of the plants 14 days after sowing and the second and third after each cut.

In the first growth of the plants after thinning, the soil was fertilised with the micronutrients boron, copper, zinc and molybdenum, whose sources were boric acid, copper chloride, zinc chloride and sodium molybdate in doses of 1.39, 2.61, 2.03 and 0.36 mg $dm^{-3}$, respectively.

Three cuts were made in the shoots of the grasses at intervals of 30 days. The first cut was made 30 days after plant emergence. The shoots were cut 5 cm from the stem of each plant for the first and second cuts, and near the lap of the plant in the third cut.

After each cut, the plant material was harvested, packed in paper bags, properly identified and subjected to oven drying by forced air circulation at 65°C for 72 h until a constant mass (Silva and Queiroz, 2002), after which it was weighed to determine the dry weight. The same procedure was repeated for the second and third cuts.

In the third grass cutting, the shoot mass was also retained to collect the plant roots. The roots were separated from the shoots and washed in water under a set of sieves of 1.00 and 0.25 mm to remove the earth. The shoots and roots were placed in paper bags, labelled, weighed and dried in an oven using the same methodology as that of the shoot. The concentrations of nitrogen, phosphorus and potassium in the shoots and roots of grasses were determined according to the methodology proposed by Malavolta et al. (1997). The variables were the concentrations of nitrogen, phosphorus and potassium in the shoots and roots of the Marandu and Xaraes grasses.

The results were subjected to an analysis of variance at a 5% probability, and a regression test for quantitative variables (dose wood ash) and Tukey's test for qualitative variables (*B. brizantha*) were applied through the statistical application Sisvar (Ferreira, 2008).

## RESULTS AND DISCUSSION

The concentrations of nitrogen, phosphorus and potassium in the shoots and roots of the Marandu and Xaraes grasses were significant. In the shoots, there was an interaction effect between the grasses and wood ash doses regarding the concentrations of nitrogen and potassium. In the roots, an interaction between these factors occurred only regarding the nitrogen concentration (Table 1).

In the three sections of the plants, the nitrogen concentrations in the shoots were adjusted to model linear and quadratic regressions. In the first cut of grasses, the nitrogen concentration in the shoots of Xaraes increased by 65.13% when treated with 15 g $dm^{-3}$ ash compared to plants with no application to this residue (Figure 1A). For the Marandu grass, the results were not reported by any regression model.

In the second cut, the nitrogen concentrations in shoots were adjusted to model a linear regression (Figure 1B); this concentration was adjusted to model linear and quadratic regressions in the third cut. In the second and third cuts, the concentration of nitrogen the shoots of Marandu and Xaraes decreased (Figure 1C).

The concentration of nitrogen in the first cut of the plants increased in Xaraes from 8.29 to 23.77 g $kg^{-1}$

**Table 1.** Concentration of nitrogen, phosphorus and potassium in the shoots and roots of grasses Marandu and Xaraes a function of doses wood ash.

| Nutrient | Source of variation | | | Cuts | Coefficient of variation (%) |
|---|---|---|---|---|---|
| | Grass forage | Doses of wood ash | Interaction | | |
| Nitrogen shoot | 0.0000*** | 0.0000*** | 0.0000*** | 1º | 15.56 |
| | 0.3707$^{ns}$ | 0.0000*** | 0.0004** | 2º | 15.50 |
| | 0.2723$^{ns}$ | 0.0000*** | 0.0742$^{ns}$ | 3º | 15.85 |
| Root | 0.0000*** | 0.0000*** | 0.0004** | 3º | 17.72 |
| Phosphorus shoot | 0.0013** | 0.4537$^{ns}$ | 0.5819$^{ns}$ | 1º | 32.46 |
| | 0.0000*** | 0.0769$^{ns}$ | 0.1583$^{ns}$ | 2º | 33.01 |
| | 0.0000*** | 0.0000*** | 0.1000$^{ns}$ | 3º | 24.41 |
| Root | 0.0698$^{ns}$ | 0.0009** | 0.1023$^{ns}$ | 3º | 17.73 |
| Potassium shoot | 0.6446$^{ns}$ | 0.0000*** | 0.0195* | 1º | 10.82 |
| | 0.6881$^{ns}$ | 0.0004** | 0.9925$^{ns}$ | 2º | 9.95 |
| | 0.0925$^{ns}$ | 0.0011* | 0.8488$^{ns}$ | 3º | 11.54 |
| Root | 0.3516$^{ns}$ | 0.0000*** | 0.2923$^{ns}$ | 3º | 4.14 |

$^{ns}$ Not significant by F test at 0.05 probability. ***, **, * Significant at 0.1, 1 and 5% probability level by F test, respectively.

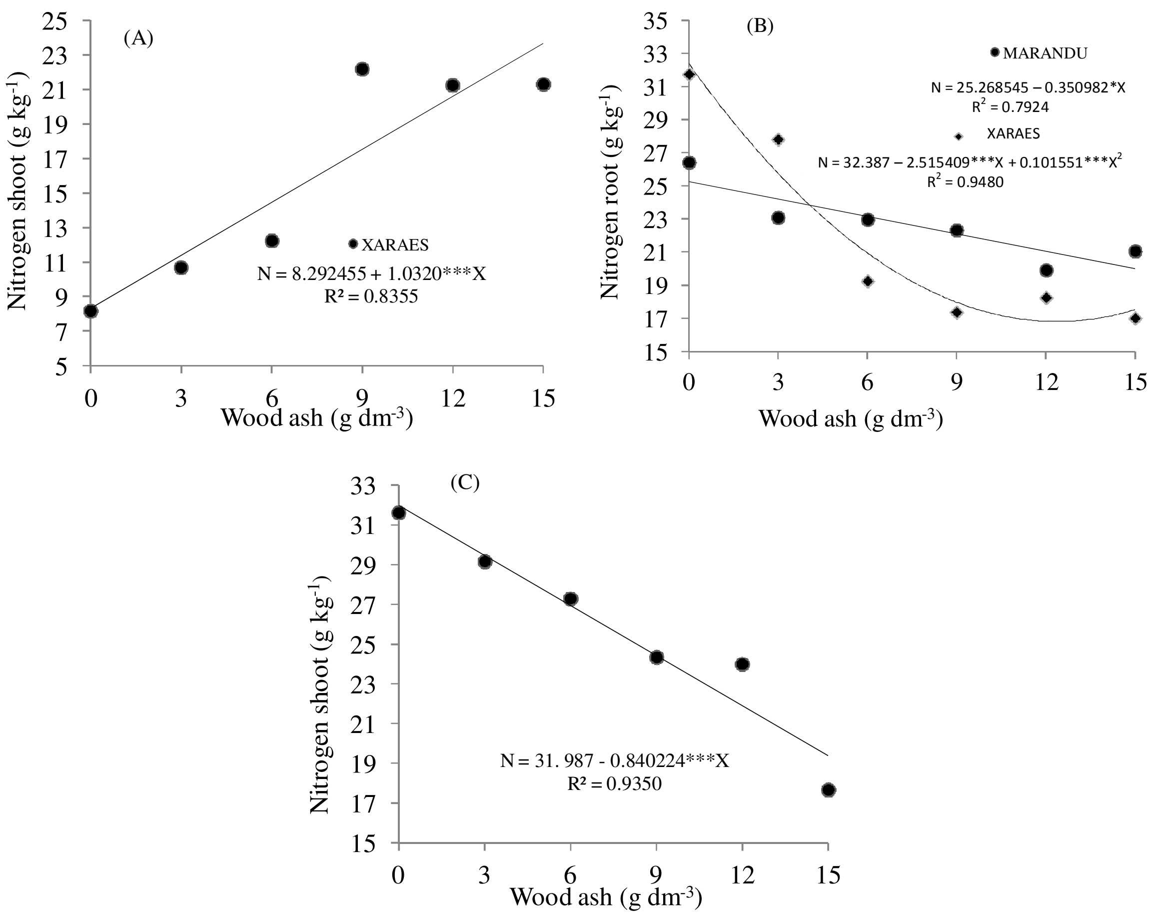


**Figure 1.** Nitrogen concentration in shoots of grasses marandu and xaraes a function of doses wood ash on the first (A), second (B) and third (C) cuts. ***. **. * Significant at 0.1, 1 and 5% probability level, respectively.

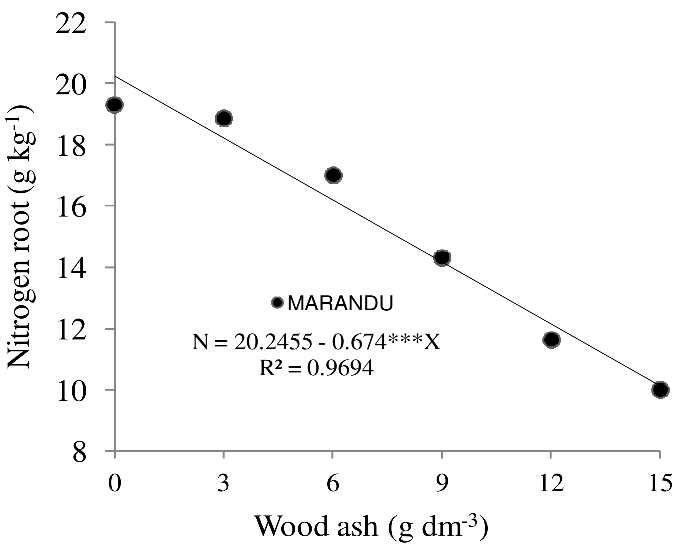


**Figure 2.** Concentration of nitrogen in root Marandugrass in function of the doses wood ash in third cut. *** Significant at 0.1% probability.

depending on the doses of wood ash up to 15 g $dm^{-3}$. Thus, as all of the plots were fertilised with 200 mg $dm^{-3}$ nitrogen, the fertilisation with the wood ash contributed to the uptake of nitrogen by this forage.

Costa et al. (2009) observed in the shoots of Marandu grass a nitrogen concentration of 16.18 g $kg^{-1}$ at a dose of 200 kg $ha^{-1}$ $year^{-1}$. Oliveira et al. (2005) and Cesar et al. (2006) found foliar nitrogen concentrations of 19.50 and 19.80 g $kg^{-1}$, respectively, for the Marandu and Xaraes grasses at nitrogen levels of 210 and 200 kg $ha^{-1}$.

In the experimental interval of the doses of vegetable ash in this study, a 3 to 15 g $dm^{-3}$ concentration of nitrogen at a dose of 9 g $dm^{-3}$ corresponds to 17.58 g $kg^{-1}$. Thus, it appears that, on average, fertilisation of the Marandu and Xaraes grasses with vegetal ash helped the plants to absorb nitrogen in amounts similar to those observed by Costa et al. (2009), Oliveira et al. (2005) and Cesar et al. (2006), who used mineral fertiliser.

In the second cut of grasses, the nitrogen concentration decreased from 25.27 to 20 g $kg^{-1}$ depending on the dose of wood ash. In the third cut, the nitrogen concentration in the Marandu and Xaraes grasses decreased from 31.99 to 19.38 g $kg^{-1}$. The concentration of nitrogen in the leaves of the Marandu grass is between 13 and 20 g $kg^{-1}$ (Werner et al., 1997); therefore, nitrogen concentrations in shoots of the three cuts of grasses were within the range proposed by this author.

The nitrogen concentrations of roots of the Marandu grass were adjusted to a linear regression model. There was a decrease of 99.70% nitrogen in the roots of this grass when comparing the dose of 15 g $dm^{-3}$ wood ash treatment with no application of this residue. For the corresponding Xaraes grass, there was no adjustment to a regression model (Figure 2).

In the roots of the Marandu and Xaraes grasses, the concentration of nitrogen decreased from 20.24 to 10.13 g $kg^{-1}$. Bonfim-Silva and Monteiro (2010), studying combinations of nitrogen and sulphur in the roots of signal grass, observed as a result of a nitrogen dose of 275 mg $dm^{-3}$ in isolated effect, a concentration of 8.42 g $kg^{-1}$ the roots of this grass. In the present study, the wood ash promoted significant changes in the nitrogen concentration in the roots of the Marandu grass, indicating the need for studies of the influence of this residue on the mineral nutrition of this grass.

The concentration of phosphorus in the shoots of the Marandu and Xaraes grasses had an isolated effect. The phosphorus concentration in the shoots increased significantly in all of the cuts and was significant in the Marandu grass, thus evidencing the distinct nutritional needs of *B. brizantha* in the absorption and assimilation of phosphorus (Table 2).

The phosphorus concentration in the shoots of the Marandu grass indicated by Werner et al. (1997) is between 0.8 and 3.0 g $kg^{-1}$. Malavolta et al. (1997) reported that the required phosphorus for plant varies from 1 to 5 g $kg^{-1}$. The phosphorus concentration observed in the present study in the first cut of the plants (Table 2) is below the range described by these authors.

The lower concentration of phosphorus in the first cut of grasses when compared to the other cuts may be due to the application of this nutrient for forage for the formation of the root system, resulting in lower concentrations in the shoots in the first cut. Thus, the phosphorus concentration in third cut is within the range considered adequate for forage.

When the phosphorus concentration of the Marandu and Xaraes grasses was adjusted to the linear regression model, 38.78% of this increase occurred in both nutrient forages when comparing the 15 g $dm^{-3}$ treatment with no application of wood ash (Figure 3).

For the phosphorus concentration in the roots of the Marandu and Xaraes grasses, the effect of the wood ash dose on the grasses was significant when adjusted to a quadratic regression model with a maximum wood ash concentration of 12 g $dm^{-3}$. The concentration of phosphorus increased by 25.17% in the roots of these grasses when comparing the 15 g $dm^{-3}$ dose with treatment without this residue (Figure 4).

The potassium concentration in the shoots of the Marandu and Xaraes grasses significantly interacted with the grasses and wood ash doses in the first cut. The potassium concentration in the shoot was adjusted to a quadratic model of regression. In the first cut, the maximum concentration of potassium in the shoots of the Marandu grass was observed at a dose of wood ash of 11.93 g $dm^{-3}$, with increases in the potassium concentration as a function of the doses of wood ash of 36.12 and 42.70%, respectively, for the Marandu and Xaraes grasses (Figure 5A).

In the second and third cuts, the potassium concentration in the shoots was adjusted to a linear

**Table 2.** Phosphorus (gkg$^{-1}$) in the shoot of the grasses Marandu and Xaraes in first, second and third cuts.

| Phosphorus shoot (gkg$^{-1}$) | | | |
|---|---|---|---|
| **Cuts** | **Marandu** | **Xaraes** | **CV%** |
| First cut | 0.40$^a$ | 0.26$^b$ | 32.46 |
| Second cut | 1.37$^a$ | 0.93$^b$ | 33.61 |
| Third cut | 1.92$^a$ | 1.27$^b$ | 24.41 |

Means followed by lower case online differ by Tukey test at 5% probability. CV% = coefficient of variation.

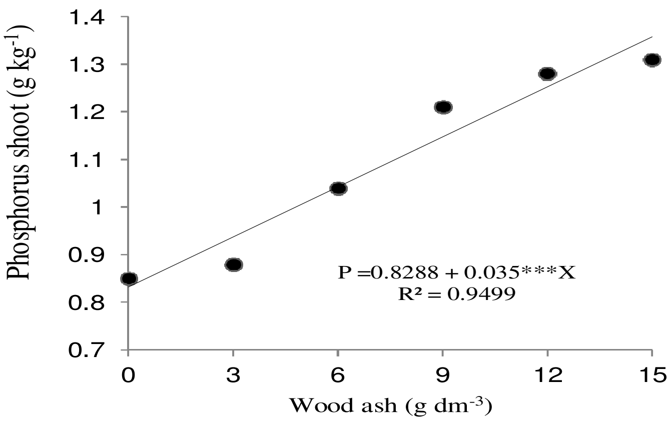


**Figure 3.** Concentration of phosphorus in shoots of grasses Marandu and Xaraes on third cut, in function of the doses of wood ash. *** Significant at 1% probability.

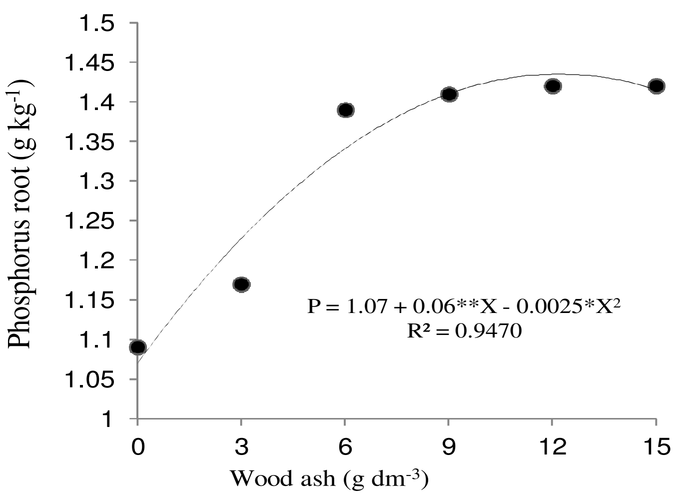


**Figure 4.** Concentration of phosphorus in roots of grasses Marandu and Xaraes on function of the doses wood ash, in the third cut. **, * Significant at 1 and 5% probability level, respectively.

regression model. There was a reduction of 17.99% potassium in the shoots of the grasses (Figure 5B). In the third cut, the potassium concentration in the shoots of the Marandu and Xaraes grasses increased from 9.48 to 11.46 g kg$^{-1}$, an increase of 17.28%, when comparing the highest dose of wood ash, 15 g dm$^{-3}$, and treatment without fertilisation (Figure 5C).

In the first cut of the Xaraes grass, the potassium concentration was between 17.47 and 30.32 g kg$^{-1}$ by comparing the maximum dose of wood ash and treatment without application with this residue. In the second cut, there was a reduction of potassium of 13.38 to 11.34 g kg$^{-1}$ in both forages; however, in the third cut, this nutrient increased in the shoots as a function of the dose of wood ash (Figure 5C).

Mattos and Monteiro (1998), under the controlled cultivation of the *B. brizantha* Marandu grass, observed in a nutrient solution of the leaves of this grass decreases in the potassium concentration from 20 to 10% and from 26 to 9%, respectively, in the first and second cuts of forage.

For Werner et al. (1997), the potassium concentrations considered adequate for Marandu grass sheets ranged from 12 to 30 g kg$^{-1}$. Ferrari Neto (1991) specifies as suitable potassium concentrations of 11 g kg$^{-1}$ in all aerial parts of *B. brizantha*. Thus, the potassium concentrations in the shoots of Marandu grass in the three cuts in this study are in agreement with the value proposed by Ferrari Neto (1991).

The potassium concentration in the roots of grasses was significant only when adjusted to the quadratic regression model, and greater concentrations were observed at a dose of wood ash of 13.58 g dm$^{-3}$. Increments of 35.93% provided the highest concentration of potassium in the shoots of grasses treated without fertilisation with this residue (Figure 6).

A potassium concentration of 25 g kg$^{-1}$ in the roots of the Marandu grass at a dose of potassium in mineral fertiliser of 234 mg L$^{-1}$ was observed by Monteiro et al. (1995). In the present study, the concentration of potassium in the roots of grasses is 29.17 g kg$^{-1}$; this result can be attributed to considerable amounts (compared to other nutrients) of potassium in the constitution of the wood ash used in this study.

## Conclusions

The concentrations of nitrogen, phosphorus and

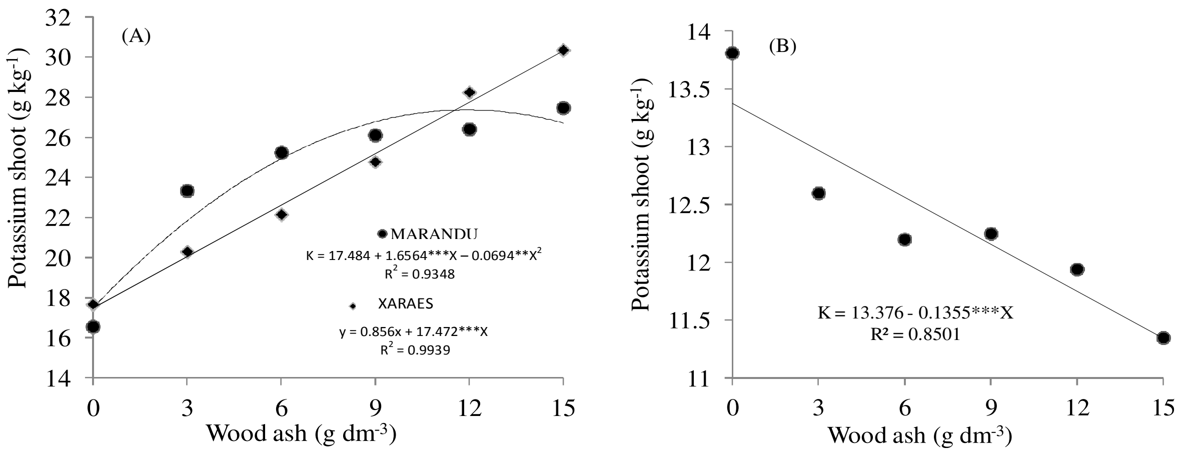


**Figure 5.** Concentration of potassium in the shoots of grasses marandu and xaraes on function of the doses the wood ash, in the first, second and third cut. *** Significant at 0.1 and 1% probability.

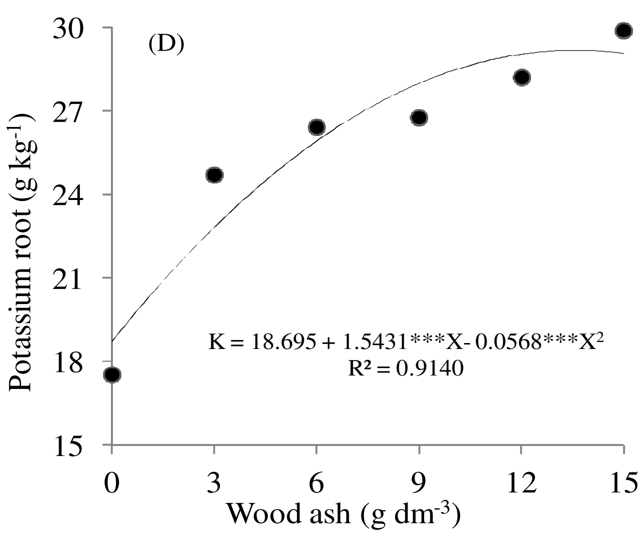


**Figure 6.** Concentration of potassium in the roots of grasses Marandu and Xaraes on function of the doses the wood ash, in the third cut. *** Significant at 0.1 % probability level, respectively.

potassium in the shoots of the tropical Marandu and Xaraes grasses as a function of the dose the wood ash are in accordance with the concentration ranges considered appropriate for the grasses studied.

The wood ash as fertiliser promotes significant changes in the nutritional characteristics of the tropical Marandu and Xaraes grasses, increasing the concentrations of nitrogen, phosphorus and potassium in forage grasses.

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*Full Length Research Paper*

# A simple and rapid screening technique for grain β carotene content in pearl millet through spectrophotometric method

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**Pearl millet ranks sixth in annual world cereal production. Vitamin A deficiency is a global health problem affecting 140-250 million children and accounts for increased childhood mortality and diseases. Humans and animals are unable to synthesize Vitamin 'A' requirement as plant-derived-carotene are metabolized to produce Vitamin 'A'. Pearl millet grains are rich nutritionally and contain sufficient amount of β carotene which is the precursor of Vitamin A. In order to satisfy the recommended dietary allowance, the targeted level of beta carotene in pearl millet (20 µg/ g of grain), screening of large number of pearl millet genotypes is a prerequisite. Among the various available techniques, high performance liquid chromatography (HPLC) can be accurate for β carotene estimation; however it is laborious, time consuming and requires skilled labour and use of highly toxic solvents. The aim of this work is to develop a simple and rapid screening method for determination of β-carotene in pearl millet by spectrophotometry. Two hundred recombinant inbred lines developed from the cross between agronomically superior inbred line (PT 6029) and high beta carotene golden millet line (PT 6129) were evaluated at Department Vitamin A of Millets, Tamil Nadu Agricultural University, Coimbatore. The range of β carotene varied between 0.46 and 2.83 µg/g of grain. Eighty recominant inbred lines (RILs) exceeded the general mean of 1.7 µg/g of grain and 17 transgressive recombinants were obtained. These transgressive recombinants could be used in conventional plant breeding programme for development of inbred lines with high beta carotene and yield in order to meet requirement in the diet.**

**Key words:** Pearl millet, β carotene, Vitamin A, recominant inbred lines (RILs), spectrophotometer, transgressive segregates.

## INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] known as bulrush or cattail millet, is the most important among a number of unrelated millet species grown for food worldwide (Angarawai et al., 2008). In India pearl millet is fifth most important grain crop next to rice, wheat, maize and sorghum. It is grown in more than 8.39 million hectares with current grain production of 9.5 million tonnes and productivity of 1091 kg/ha (Directorate of Economics and Statistics, 2011-2012). Carotenoids are C40 isoprenoid polyene compounds that form lipid soluble yellow, orange and red pigments. One of the most important physiological functions of carotenoids in human nutrition is to act as pro-Vitamin A (Vitamin A precursors like alpha carotene, beta carotene and beta cryptoxanthin).

Many studies show strong correlations between

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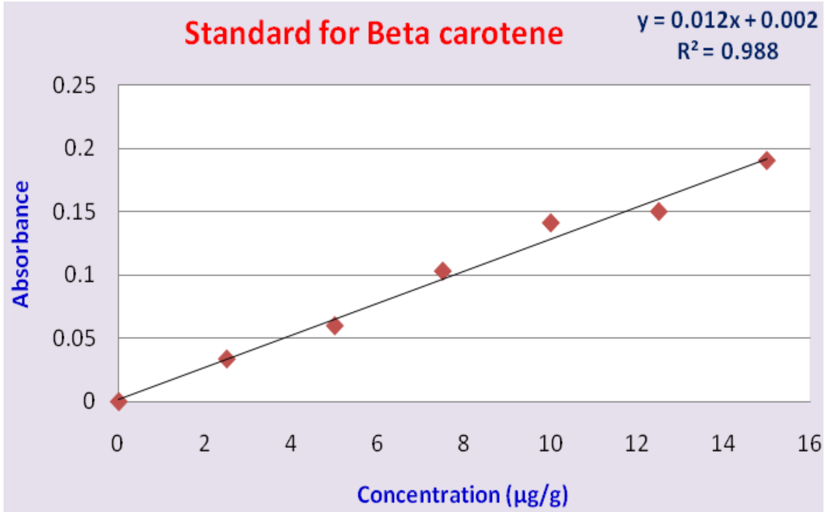


**Figure 1.** β Carotene standard graph.

carotenoids intake and a reduced risk of some diseases, such as cancer, atherogenesis bone calcification, eye degeneration, immune function and neuronal damage. Among the carotenoids, β-carotene is popular to consumers because bioconversion of beta carotene into Vitamin A is high as compare to other carotene (Karnjanawipagul et al., 2010). Vitamin A deficiency causes hundreds of thousands of cases of irreversible blindness every year, especially among children in developing countries. Humans and animals are unable to synthesize their own Vitamin 'A' requirement. Plant derived carotene are metabolized to produce Vitamin 'A'. Pearl millet grain is very rich nutritionally and contains higher protein content than many other cereals. Besides protein, pearl millet grains also contain sufficient amount of beta-carotene which is the precursor of Vitamin A. Pearl millet is a good source of fat soluble Vitamins, though not much information is available on Vitamins, the beta carotene content was reported to be 0.1 µg/g (Khalil and Sawaya, 1984), and thus, it can serve as an additional source of Vitamin A.

In order to overcome the malnutrition problem and satisfy the recommended dietary allowance the targeted level of beta carotene content in pearl millet 20 µg/g of grain (Bouis et al., 2011), screening of large number of pearl millet genotypes is a prerequisite. In order to achieve the target, our aim to screen the large number of pearl millet genotypes. Different methods have been proposed for the analysis of carotenoids including β-carotene. Among the various available techniques, high performance liquid chromatography (HPLC) can be accurate, however it is laborious, time consuming and requires skilled labour and use of highly toxic solvents (Karnjanawipagul et al., 2010). The aim of this work is to develop a simple and rapid screening method for determination of β-carotene in pearl millet by spectrophotometry.

## MATERIALS AND METHODS

The experimental material consisted of a recombinant inbred lines (RILs) derived from the cross between PT 6029 an agronomically superior inbred line and PT 6129 a high beta carotene golden millet line. The RIL population which consist of 200 individuals was developed through ear to row method. The experiment was laid out in homogeneous block following randomized block design replicated twice with 200 RILs and parents during summer, 2013 at the Department of Millets, Tamil Nadu Agricultural University, Coimbatore. Sefled seeds from 200 RILs were used for beta carotene estimation through spectrophotometric method. The estimation of beta carotene in this study was followed as described by Sandra et al. (1955) with minor modifications. This modified protocol has been standardized in pearl millet for beta carotene estimation.

### Standard and sample preparation

In a 100 ml volumetric flask, 25 mg of β carotene was weighed and it was dissolved and made up to the mark with water saturated n-butanol (WSB). 8 ml of the above homogeneous solution was then pipetted into a 100 ml volumetric flask which was made up to the mark with water saturated n-butanol. Twenty-five millimeter of this solution was taken and placed in a 100 ml volumetric flask and made up with water saturated n-butanol. With the suitable dilution of the standard solution with water saturated n-butanol in 10 ml volumetric flasks (e.g from 0.5 ml to 3 ml of standard solution in 10 ml) the calibration curve was prepared (The standard solution has the concentration of 5 µg of β carotene/ml). The absorbance of each dilution was measured and the calibration curve was established (Figure 1).

The pearl millet grain from each of the 200 RILs was collected and a small quantity of it was thoroughly grinded to make fine flour to estimate the β carotene content. 10 gram of the flour from each of the RILs was taken into 100 ml of conical flask and 40 ml of water saturated n-butanol was added. The conical flask was covered with aluminium foil in order to maintain dark condition. The content of the flask was mixed vigorously for 1 min and kept for overnight at room temperature for complete extraction of β carotene. Next day the content was shaken well and filtered completely through Whatman No 40 filter paper. The optical density

**Table 1.**β carotene content (mean of two replication) of Parents and RILs in Pearl millet.

| S/N | RILs | Content (µg/g) | Colour of the grain | S/N | RILs | Content (µg/g) | Colour of the grain | S/N | RILs | Content (µg/g) | Colour of the grain | S/N | RILs | Content (µg/g) | Colour of the grain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | PT 6029 | 0.46 (0.43) | G | 26 | RIL24 | 1.39 | YB | 51 | RIL49 | 0.73 | YB | 76 | RIL74 | 1.99 | YB |
| 2 | PT 6129 | 2.53 | Y | 27 | RIL25 | 1.70 | C | 52 | RIL50 | 1.00 | YB | 77 | RIL75 | 1.48 | Y |
| 3 | RIL 1 | 1.14 | Y | 28 | RIL26 | 1.14 | YB | 53 | RIL51 | 1.59 | C | 78 | RIL76 | 1.50 | Y |
| 4 | RIL2 | 1.27 | GB | 29 | RIL27 | 0.51 | YB | 54 | RIL52 | 2.25 | C | 79 | RIL77 | 2.72 (2.60) | Y |
| 5 | RIL3 | 1.21 | GB | 30 | RIL28 | 0.85 | DG | 55 | RIL53 | 2.83 | YB | 80 | RIL78 | 2.53 | Y |
| 6 | RIL4 | 1.47 | G | 31 | RIL29 | 1.33 | Y | 56 | RIL54 | 1.43 | YB | 81 | RIL79 | 1.45 | YB |
| 7 | RIL5 | 1.14 | GB | 32 | RIL30 | 2.11(2.06) | YB | 57 | RIL55 | 1.59 | YB | 82 | RIL80 | 1.41 | Y |
| 8 | RIL6 | 1.30 | Y | 33 | RIL31 | 1.64 | YB | 58 | RIL56 | 1.16 | Y | 83 | RIL81 | 2.72 | YB |
| 9 | RIL7 | 1.24 | GB | 34 | RIL32 | 1.52 | Y | 59 | RIL57 | 1.06 (0.97) | C | 84 | RIL82 | 2.66 (2.54) | C |
| 10 | RIL8 | 1.66 | Y | 35 | RIL33 | 0.89 | Y | 60 | RIL58 | 1.62 | C | 85 | RIL83 | 1.71 | C |
| 11 | RIL9 | 0.87 | Y | 36 | RIL34 | 1.25 | Y | 61 | RIL59 | 1.28 | G | 86 | RIL84 | 1.62 | C |
| 12 | RIL10 | 2.28 (2.18) | C | 37 | RIL35 | 1.26 | GB | 62 | RIL60 | 1.88 | YB | 87 | RIL85 | 1.57 | C |
| 13 | RIL11 | 2.71 | Y | 38 | RIL36 | 1.39 | Y | 63 | RIL61 | 1.46 | Y | 88 | RIL86 | 1.69 | Y |
| 14 | RIL12 | 2.83 | G | 39 | RIL37 | 1.70 | YB | 64 | RIL62 | 1.97 | YB | 89 | RIL87 | 0.81 | C |
| 15 | RIL13 | 1.48 | Y | 40 | RIL38 | 1.97(1.86) | YB | 65 | RIL63 | 1.45 | G | 90 | RIL88 | 1.64 | Y |
| 16 | RIL14 | 1.63 | G | 41 | RIL39 | 2.43 | DG | 66 | RIL64 | 1.10 | Y | 91 | RIL89 | 1.63 (1.58) | Y |
| 17 | RIL15 | 1.01 | C | 42 | RIL40 | 2.68 | G | 67 | RIL65 | 1.61 | Y | 92 | RIL90 | 1.36 | C |
| 18 | RIL16 | 1.01 | YB | 43 | RIL41 | 1.64 | C | 68 | RIL66 | 1.68 | Y | 93 | RIL91 | 1.59 | YB |
| 19 | RIL17 | 1.40 | YB | 44 | RIL42 | 1.67 | G | 69 | RIL67 | 2.21 | G | 94 | RIL92 | 1.26 | Y |
| 20 | RIL18 | 2.05 | YB | 45 | RIL43 | 1.81 | Y | 70 | RIL68 | 2.08 | G | 95 | RIL93 | 1.96 | Y |
| 21 | RIL19 | 0.77(0.68) | YB | 46 | RIL44 | 2.10 | Y | 71 | RIL69 | 1.67 | G | 96 | RIL94 | 1.42 | YB |
| 22 | RIL20 | 2.11 | Y | 47 | RIL45 | 2.74 | YB | 72 | RIL70 | 1.64 | GY | 97 | RIL95 | 2.23 | G |
| 23 | RIL21 | 2.46 | YB | 48 | RIL46 | 1.71 | YB | 73 | RIL71 | 1.23(1.20) | C | 98 | RIL96 | 1.47 | YB |
| 24 | RIL22 | 1.75 | Y | 49 | RIL47 | 0.98 | Y | 74 | RIL72 | 2.62 | YB | 99 | RIL97 | 1.75 (1.68) | YB |
| 25 | RIL23 | 1.01 | C | 50 | RIL48 | 2.31(2.20) | Y | 75 | RIL73 | 2.54 | Y | 100 | RIL98 | 1.75 | YB |
| **S/N** | **RILs** | **Content (µg/g)** | **Colour of the grain** | **S/N** | **RILs** | **Content (µg/g)** | **Colour of the grain** | **S/N** | **RILs** | **Content (µg/g)** | **Colour of the grain** | **S/N** | **RILs** | **Content (µg/g)** | **Colour of the grain** |
| 101 | RIL99 | 1.14 | Y | 127 | RIL125 | 1.11 | YB | 153 | RIL151 | 1.60 | Y | 179 | RIL177 | 1.42 (1.26) | Y |
| 102 | RIL100 | 1.68 | C | 128 | RIL126 | 1.00 | Y | 154 | RIL152 | 1.41 | Y | 180 | RIL178 | 1.66 | Y |
| 103 | RIL101 | 0.85 | Y | 129 | RIL127 | 1.18 | G | 155 | RIL153 | 1.57 | YB | 181 | RIL179 | 1.73 | YB |
| 104 | RIL102 | 0.56 | YB | 130 | RIL128 | 1.92 | C | 156 | RIL154 | 2.06 | DG | 182 | RIL180 | 1.66 | YB |
| 105 | RIL103 | 0.46 | Y | 131 | RIL129 | 1.58 | Y | 157 | RIL155 | 1.41 | Y | 183 | RIL181 | 0.96 | Y |
| 106 | RIL104 | 1.07 | Y | 132 | RIL130 | 1.97 | G | 158 | RIL156 | 1.56 | Y | 184 | RIL182 | 1.66 | YB |

**Table 1.** Contd.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 107 | RIL105 | 0.76 | C | 133 | RIL131 | 1.44 | YB | 159 | RIL157 | 1.49 | Y | 185 | RIL183 | 1.20 | G |
| 108 | RIL106 | 0.83 | YB | 134 | RIL132 | 2.21 | Y | 160 | RIL158 | 1.57 (1.50) | Y | 186 | RIL184 | 1.45 | G |
| 109 | RIL107 | 0.95 | C | 135 | RIL133 | 1.91 | YB | 161 | RIL159 | 1.70 | Y | 187 | RIL185 | 1.45 | G |
| 110 | RIL108 | 1.90 (1.86) | YB | 136 | RIL134 | 2.70 | YB | 162 | RIL160 | 1.43 | Y | 188 | RIL186 | 1.84 (1.78) | YB |
| 111 | RIL109 | 1.78 | C | 137 | RIL135 | 2.57 (2.52) | YB | 163 | RIL161 | 1.57 | Y | 189 | RIL187 | 2.04 | YB |
| 112 | RIL110 | 1.81 | Y | 138 | RIL136 | 2.47 | YB | 164 | RIL162 | 1.55 | Y | 190 | RIL188 | 1.28 | YB |
| 113 | RIL111 | 2.25 | Y | 139 | RIL137 | 2.45 | YB | 165 | RIL163 | 2.31 | Y | 191 | RIL189 | 2.45 | Y |
| 114 | RIL112 | 1.02 | C | 140 | RIL138 | 1.94 | Y | 166 | RIL164 | 1.76 | Y | 192 | RIL190 | 2.45 | Y |
| 115 | RIL113 | 1.67 | G | 141 | RIL139 | 2.66 | YB | 167 | RIL165 | 1.28 (1.20) | G | 193 | RIL191 | 2.33 | YB |
| 116 | RIL114 | 1.58 | YB | 142 | RIL140 | 1.92 | Y | 168 | RIL166 | 1.58 | Y | 194 | RIL192 | 1.73 | YB |
| 117 | RIL115 | 0.86 | G | 143 | RIL141 | 1.39 | Y | 169 | RIL167 | 1.65 | G | 195 | RIL193 | 1.75 | G |
| 118 | RIL116 | 0.55 | YB | 144 | RIL142 | 1.49 | Y | 170 | RIL168 | 1.88 | Y | 196 | RIL194 | 2.70 | YB |
| 119 | RIL117 | 0.62 | C | 145 | RIL143 | 1.58 | Y | 171 | RIL169 | 1.59 | YB | 197 | RIL195 | 2.32 | YB |
| 120 | RIL118 | 0.83 | C | 146 | RIL144 | 1.73 (1.58) | G | 172 | RIL170 | 1.51 | YB | 198 | RIL196 | 1.94 (1.92) | YB |
| 121 | RIL119 | 1.91 (1.88) | YB | 147 | RIL 145 | 1.66 | G | 173 | RIL171 | 2.12 | YB | 199 | RIL197 | 2.15 | YB |
| 122 | RIL120 | 0.62 | C | 148 | RIL146 | 1.68 (1.55) | Y | 174 | RIL172 | 1.82 (1.65) | Y | 200 | RIL198 | 2.61 | G |
| 123 | RIL121 | 1.42 | C | 149 | RIL147 | 1.33 | Y | 175 | RIL173 | 2.59 | YB | 201 | RIL199 | 1.91 | Y |
| 124 | RIL122 | 1.47 | YB | 150 | RIL148 | 1.41 | Y | 176 | RIL174 | 2.68 | G | 202 | RIL200 | 1.75 | Y |
| 125 | RIL123 | 1.72 | C | 151 | RIL149 | 2.00 | Y | 177 | RIL175 | 1.42 | YB | | | | |
| 126 | RIL124 | 2.06 | G | 152 | RIL150 | 1.91 | Y | 178 | RIL176 | 1.74 | YB | | | | |

G - Gray, Y - Yellow, C - Cream, YB - yellow Brown, GB - Gray Brown and DG - Deep Gray.

of clear filtrate of the sample from 200 RILs was measured at 440 nm using SL 150 UV VIS Spectrophotometer. Pure water saturated n-butanol was used as the blank.

## RESULTS AND DISCUSSION

Plant carotenoids are the primary source of provitamin A with β carotene as the most well known source of it. A lack of β carotene is a major cause of Vitamin A deficiency (Julie et al., 2009). Vitamin A deficiency (VAD) causes about 70% of childhood deaths worldwide and blindness in 0.25 to 0.5 million children every year (Vignesh et al., 2012). Vitamin A as a key factor in our health plays an important role in vision, bone growth, reproduction and cell division. It also regulates the immune system. Association of β carotene in staple crops shows lower risk to Vitamin A deficiency and cancer (Yan et al., 2010). It was reported earlier that in pearl millet flour, the amount of beta carotene was found to be less than 0.01 mg/100 g (0.1 ppm) (Khalil and Sawaya, 1984). Highest beta carotene content was reported in a high yielding hybrid which recorded a beta carotene content of 36.7 µg/100 g (0.36 ppm) (Khangura et al., 1980). Comparative studies between the traditional landraces versus improved varieties revealed that the concentration of beta carotene was highest in the improved varieties with a beta carotene content of 0.13 µmol $kg^{-1}$ (Buerkert et al., 2001).

Though, pearl millet contains beta-carotene, it is very less compared to other cereal crops especially maize. This emanated the thought that enhancing the beta-carotene content in pearl millet is feasible. Pearl millet has a vast reservoir of genetic variability for various qualitative and quantitative traits. By considering above fact, the present investigation was carried out to assess the genetic variability for β carotene content among inbred lines of pearl millet. This could be the first report for the estimation of β carotene content through spectrophometric method. β carotene content in parents and RILs were presented in Table 1. The β-carotene content of the inbreds such as PT 6129 was found to be comparable to that of β-carotene content in maize as reported by Kimura et al. (2007).

Range of beta carotene in this study was recorded from 0.46 to 2.83 µg/g of grain. Santra et al. (1955) reported β carotene content in wheat (2.25 - 5.82 µg/g). Eighty RILs exceeded the general mean of 1.7 µg/g. Beta carotene estimation was repeated twice for all the samples and the result was almost similar as that of previous estimation as the value given in parenthesis (Table 1). There is no correlation between the grain colour and beta carotene content.

The value that fall outside the parental range are said to be transgressive recombinant and the number of transgressive recombinants were obtained by comparing *per se* performance of RILs to that of parents. The number of positive transgressive recombinants obtained for beta carotene are RIL 12 and RIL 53 (2.83 µg/g), followed by RIL 47 (2.74 µg/g), RIL 77 and RIL 81 (2.72 µg/g), RIL 11 (2071 µg/g), RIL 194 and RIL 134 (2.70 µg/g), RIL 174 and RIL 40 (2.68 µg/g), RIL 139 and RIL 82 (2.66 µg/g), RIL 72 (2.62 µg/g), RIL 198 (2.61 µg/g), RIL 173 (2.59 µg/g), RIL 135 (2.57 µg/g) and RIL 73 with 2.54 µg/g, these lines could be used as donor in crossing programme.

Based on the present study, the RILs with better mean values for beta carotene will be helpful to developing beta carotene rich inbred lines which can be used as pre breeding material for further improvement of pearl millet. Further, the mapping population could be used for mapping of genes /QTLs for beta carotene.

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