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Modelling Effects of Residual Biochar,Groundnut shell, Rice Husk and Rice Straw on Productivity of Maize (*Zea mays* L.) for Sustainable Soil Fertility Restoration in the Guinea Savannah Zone

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THE MESSAGE

The concept of the International Fertilizer Development Center (IFDC) and approach to integrated soil fertility management as a set of agricultural practices adapted to local conditions to maximise the efficiency of nutrient and water use and improve agricultural productivity on poor fertility soils in the Sudan and Guinea savannah zones of West Africa is innovative to sustaining livelihood in rural communities. A field experiment was conducted at Nyankpala, near Tamale, Ghana during the 2014 cropping season and continued during 2015, to investigate the residual effects of available indigenous organic materials (Biochar – partially burnt rice husk, groundnut shell, Rice husk and Rice straw) in combination with supplementary mineral N fertilizer on yield components and grain yield of drought and Striga tolerant maize variety "Wang Data". It was a 4×3×3 experiment consisting of the 4 organic materials at 3 levels (2.5, 5 and 7.5 t ha-1 on dry matter basis) and 3 N fertilizer levels (0 kgN/ha, 45 kgN/ha and 90 kg/ha) laid out in a Randomised Complete Block Design with four replicates. Results showed increased maize growth and grain production on residual organic material nutrients required supplementary mineral N fertilisation. Best growth parameters, early days to 50% flowering and highest cob length, cob weight and stover weight, 100 seed weight and grain yield were obtained with 2.5 to 7.5 t/ha Biochar + 45 - 90 kgN/ha; 5 to 7.5 t/ha Rice Husk + 45 - 90 kgN/ha and 7.5 t/ha Rice Straw + 90 kgN/ha. Biochar provided the least quantitative input of 2.5 t/ha + 45 kgN/ha for maximum maize production and most efficient soil fertility management system. Correlation analysis showed good relationship between grain yield and leaf count (r=0.5699*), plant height (r=0.5340*), and height of cob attachment (r=0.5164*) and cob weight accounted for 69% of the grain yield. Overall maximum grain yield of maize was attained with 7.5 t/ha Biochar plus 90 kgN/ha as described by Eqn. 3c where grain yield = 2192 + 168.3 (Leaf Count at 9WAS) + 16.32 (Plant height at 9WAS – 82.3 (50% F). However, farmers in the Guinea savannah could apply groundnut shell or biochar at 7.5 t/ha and 45 kg N/ha to minimize cost and enhance soil fertility and maize production.

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1.0 INTRODUCTION

Maize (Zea mays L.) is the most important cultivated cereal crop in tropical sub-Saharan Africa and mostly grown under rain-fed conditions. Maize has become one of the most important cereals that have added great value to man, as it serves as food and livelihood for millions of people (Enujeke, 2013). In developed countries, maize is a source of industrial products such as corn oil, syrup, corn flour, sugar, brewers' grit and alcohol (FAO, 2008). It is the most important cereal crop produced and consumed staple food in Ghana with yearly increased production since 1965 (Morris et al., 1999; FAO, 2008). It is often processed into a wide range of foods and beverages, which are consumed as breakfast, main meals or snacks. It is also a main source of carbohydrates for poultry industries in Ghana. As an energy supplement in livestock feed, maize is cherished by various species of animals including poultry, cattle, pigs, goats, sheep and rabbits (DIPA, 2006). However, maize yield in Africa has continuously declined to as low as 1 t/ha due to rapid reduction in soil fertility and negligence in use of soil amendment materials (DIPA, 2006; Enujeke, 2013). Low inherent soil fertility has been identified as a major cause for low cereal yield in Ghana (Buri et al., 2009; Abe et al., 2010). Maobe et al. (2010) reported that maize grain yield is constrained especially by inadequate nitrogen supply caused by insufficient application of fertilizers by smallholder farmers. The soils of maize growing areas in Ghana are generally low in organic carbon (<1.5%), total nitrogen (<0.2%), exchangeable potassium (<100 mg/kg) and available phosphorus (<10 mg/kg) (Adu, 1995).

Sonetra (2002) suggested that subsistence farmers could apply organic manure directly to the soil as a natural means of recycling nutrients in order to improve soil fertility and yield of crops. Manures and fertilizers are the life wire of improved technology contributing about 50 to 60% increase in productivity of food grains in many parts of the world, irrespective of soil and agro-ecological zone (DIPA, 2006). The common technology for increasing fertilizer efficiency is integrated soil fertility management with the application of organic manure and use of legumes in the cropping system (FAO, 2008). Combination of organic and mineral fertilizer nutrients sources have been shown to result in synergistic effects and improved synchronization of nutrient release and uptake by crop for higher yields. Nambiar (1991) indicated that integrated use of organic manures and chemical NPK fertilizers would be quite promising not only in providing stability in production, but also in maintaining higher soil microbial and fertility status. Mutuo et al., (2000) reported that treatments that had received organic biomass had high residual effect of 50% grain yield enhancement. Soil fertility studies in Ghana fall short of elucidating the residual effects of organic materials. Therefore, the objective of this research was to evaluate the residual effects of the organic materials of biochar, groundnut shell, rice husk and rice straw, with and without supplementary nitrogen on yield components and yield of maize in the Guinea savannah zone of Ghana.

2.0 MATERIALS AND METHODS

Experimental site

A field experiment was carried out in 2014 and continued during 2015 cropping season at the University for Development Studies, Nyankpala Campus near Tamale, in the Guinea savannah zone of Ghana; on latitude 9°25′ 14′N, longitude 0° 58′ 42′W and altitude of 183 m (NAES, 1992). The area experiences unimodal rainfall with an annual mean rainfall of 1000 to 1022 mm. The temperature distribution is fairly uniform with mean monthly minimum of 21.9°C and a maximum of 34.1°C. It has a minimum relative humidity of 46% and maximum of 76.8%. The soil of the study site is a typical upland soil, developed from ironstone gravel and ferruginized ironstone (Adu, 1957). The soil is classified as a Hapliclixisol (FAO/UNESCO, 1997) and of the Tingoli series (Serno and van de Weg, 1985).

Experimental Design and Treatments

This was a 4×3×3 factorial experiment of 4 organic materials (biochar, groundnut shell, rice husk and rice straw) at 3 levels (2.5, 5 and 7.5 t ha-1 dry matter basis) and 3 nitrogen levels, 45 and 90 kg N/ha). The experiment was laid in a Randomized Complete Block Design in four replications. Plots measured 5 m × 5 m with 1 m alley between plots and 2 m alley between replications.

Table 1: Treatments (Organic materials were applied in 2014 with N in 2015 cropping season.

NO.	TREATMENT	NO.	TREATMENT
1	2.5 t/ha Biochar	19	2.5 t/ha Rice Husk + 45 kg/ha N
2	5 t/ha Biochar	29	5 t/ha Rice Husk + 45 kg/ha N
3	7.5 t/ha Biochar	21	7.5 t/ha Rice Husk + 45 kg/ha N
4	2.5 t/ha Groundnut Shells	22	2.5 t/ha Rice Straw + 45 kg/ha N
5	5 t/ha Groundnut Shells	23	5 t/ha Rice Straw + 45 kg/ha N
6	7.5 t/ha Groundnut Shells	24	7.5 t/ha Rice Straw + 45 kg/ha N
7	2.5 t/ha Rice Husk	25	2.5 t/ha Biochar + 90 kg/ha N
8	5 t/ha Rice Husk	26	5 t/ha Biochar + 90 kg/ha N
9	7.5 t/ha Rice Husk	27	7.5 t/ha Biochar + 90 kg/ha N
10	2.5 t/ha Rice Straw	28	2.5 t/ha Groundnut Shells + 90 kg/ha N
11	5 t/ha Rice Straw	29	5 t/ha Groundnut Shells + 90 kg/ha N
12	7.5 t/ha Rice Straw	30	7.5 t/ha Groundnut Shells + 90 kg/ha N
13	2.5 t/ha Biochar + 45 kg/ha N	31	2.5 t/ha Rice Husk + 90 kg/ha N
14	5 t/ha Biochar + 45 kg/ha N	32	5 t/ha Rice Husk + 90 kg/ha N
15	7.5 t/ha Biochar + 45 kg/ha N	33	7.5 t/ha Rice Husk + 90 kg/ha N
16	2.5 t/ha Groundnut Shells + 45 kg/ha N	34	2.5 t/ha Rice Straw + 90 kg/ha N
17	5 t/ha Groundnut Shells + 45 kg/ha N	35	5 t/ha Rice Straw + 90 kg/ha N
18	7.5 t/ha Groundnut Shells+45 kg/ha N	36	7.5 t/ha Rice Straw + 90 kg/ha N

Plate 1: Prepration of Biochar from "Kuntani

Plate 2: Rice Straw

AGRONOMIC PRACTICES

In 2015, the glyphosate herbicide was applied at 1.0 kg a.i./ha to kill regrowth vegetation followed by hoe-tillage to loosen the soil and made bonds to prevent spillage of water and nutrients between neighbourhood plots. Planting of 'Wang Data' maize variety was done on July 7, 2015. Nitrogen was applied in the form of ammonium sulphate in split dose at 14 and 35 days after planting (DAP) at the rate of 0, 45 and 90 kg/ha. Atrazine (80 WP) was applied 7 DAP. Hoe weed control was carried out thrice at 14 DAP and 35 DAP and 56 DAP.

DATA COLLECTION

Five plants were randomly selected per plot within the net plot and tagged for measurement of growth and some yield parameters. Plant height was measured at 3, 6, 9 and 12 weeks after planting (WAP), Leaf Area Index at 6 and 9 WAP, days to 50% flowering and at harvest, height of cob attachment, cob length and weight, straw weight, 100 seed weight, grain moisture content and grain yield.

Leaf Area Index: LAI was determined based on the relationship proposed by Watson (1972):

$LAI = L \times W \times N \times 0.72/A$ Eqn. 1.

Where: L = leaf length, W = leaf width, N = number of leaves per plant, A = area covered by plants and the constant 0.72.

Grain yield: At physiological maturity, maize cobs were harvested from a net plot of 4 m × 4 m and processed for grain yield determination and adjusted at 14% grain moisture using equation 2:

Adjusted grain yield (kg/ha) = Grain yield*10000m2*(100%-grain moisture content%)... Eqn.2.
16m2*(100%-14%)

STATISTICAL ANALYSIS

The data were subjected to analyses of variance using GenStat statistical package. Count data were transformed using square root transformation ($\sqrt{n} + 0.5$) to homogenize the variance before subjecting them to analysis of variance. Treatment means were separated using Least Significant Difference at 5% significant level. Correlation and regression analysis were examined.

3.0 RESULTS AND DISCUSSION

Maize Vegetative Parameters

Plant height, leaf area index and height of cob attachment were significantly influenced (p<0.05) by the combination of the effects of the residual organic materials and mineral nitrogen. Plant height and LAI were most enhanced similarly by 2 t/ha Biochar + 90 kg/ha N, 7.5 t/ha Biochar + 90 kg/ha N, 5 t/ha Rice Husk + 90 kg/ha N, 7.5 t/ha Rice Husk + 45 kg/ha N, 7.5 t/ha Rice Straw + 45 - 90 kg N/ha N (Table 3). Application of 2.5 t/ha Biochar + 90 kg/ha N, 5 t/ha Biochar + 45 - 90 kg/ha N, 7.5 t/ha Biochar + 90 kg/ha N, 2.5 t/ha Rice Husk + 90 kg/ha N, 5 t/ha Rice Husk + 90 kg/ha N, 7.5 t/ha Rice Husk + 90 kg/ha N were similar in earliness in flowering (Table 2). The effect of groundnut shell was similar to biochar in all parameters.

Significant variation in maize vegetative growth was caused by different organic materials sources and nitrogen quantities. The observed vigorous vegetative growth in 2.5 t/ha Biochar + 90 kg/ha N, 5 t/ha Biochar + 90 kg/ha N, 7.5 t/ha Biochar + 90 kg/ha N, 5 t/ha Rice Husk + 90 kg/ha N, 7.5 t/ha Rice Husk + 45 kg/ha N and 2.5 t/ha Rice Straw + 90 kg/ha N was attributed to positive effect of nitrogen on vigorous vegetative growth (Khan et al., 2008). Combined organic and nitrogen fertilization promoted maize vegetative growth in comparison to some of the organic materials alone on the control plots. Sadeghi and Bahrani (2009) observed that optimum crop growth with the highest crop residues and nitrogen rates. This result is in line with Bilalis et al. (2010) who observed an increment in plant height from residual organic sources plus inorganic fertilizers. Nwaiwu et al. (2010) also observed that organic manure in combination with inorganic fertilizer ensured increment in plant growth. These results is in accordance with the work of Bilalis et al. (2010) who observed an increase in leaf area index from the combination of residual organic sources and inorganic fertilizers over the control. Uzoma et al. (2011) reported that organic amended soils resulted in better crop establishment and positively increased crop growth rate.

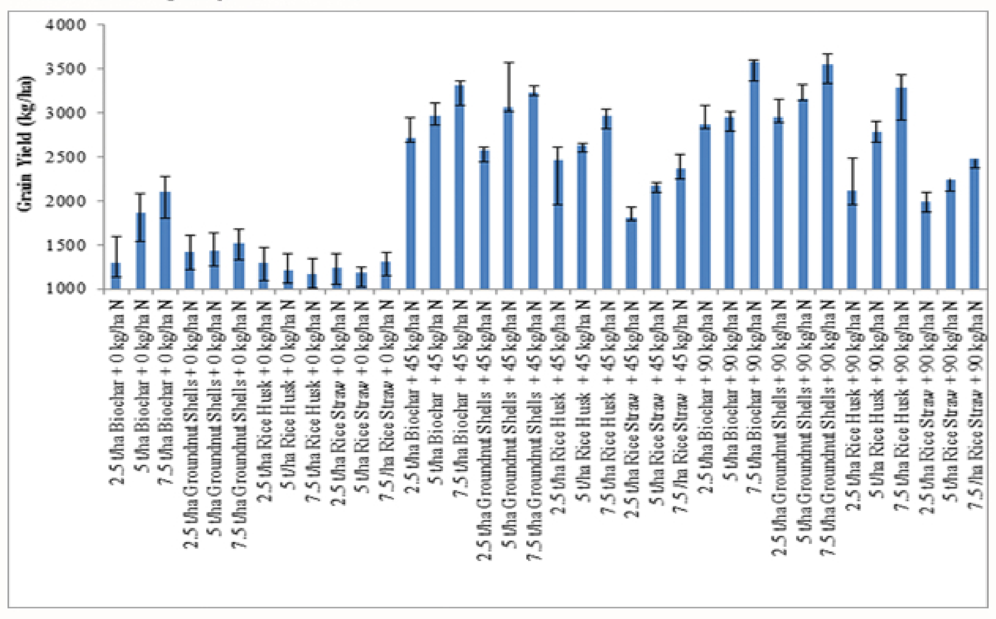
Table 2: Effect of Treatments on Plant Height, Leaf Area Index, Days to 50% flowering and Height of Cob attachment in 2015 Cropping Season.

Treatment	Plant height (cm)	LAI	Height of cob attachment (cm)	Days to 50% flowering
2.5 t/ha Biochar	163d	13.4c	82.4b	50.5bc
5 t/ha Biochar	172.6cd	15b	81.2b	49.8ab
7.5 t/ha Biochar	177.5bc	16ab	89.9b	48.8a
2.5 t/ha Groundnut shell	140.3e	12.3cd	64.6d	51.8bc
5 t/ha Groundnut shell	142.4e	12.7cd	68.3d	50.8bc
7.5 t/ha Groundnut shell	145.7e	12.8cd	66.7d	52cd
2.5 t/ha Rice husk	141.6e	9.6d	65d	53.8d
5 t/ha Rice Husk	139.3e	8.9d	56.9d	53.8d
7.5 t/ha Rice Husk	139.7e	9.8d	53.9d	54.3d
2.5 t/ha Rice Straw	140.7e	9.6d	52.9d	53.3d
5 t/ha Rice Straw	143.1e	11.2cd	60.8d	53d
7.5 t/ha Rice Straw	146.6e	11.2cd	61.8d	53.5d
2.5 t/ha Biochar + 45 kg/ha N	180.1b	17.3a	94.5ab	49.5ab
5 t/ha Biochar + 45 kg/ha N	181.2b	17.9a	97.7ab	48.5a
7.5 t/ha Biochar + 45 kg/ha N	197.7a	18.8a	100.7a	48.8a
2.5 t/ha Groundnut Shell + 45 kg/ha N	177.2bc	16.3ab	86.4b	50.5bc
5 t/ha Groundnut Shell + 45 kg/ha N	177.6bc	17.3a	74.7cd	49.5ab
7.5 t/ha Groundnut Shell + 45 kg/ha N	183b	18.6a	91.3b	50.3bc
2.5 t/ha Rice Husk + 45 kg/ha N	169.9cd	14.1ac	77.7c	50abc
5 t/ha Rice Husk + 45 kg/ha N	177.7bc	16.6ab	85.8b	50.8bc
7.5 t/ha Rice Husk + 45 kg/ha N	187.7ab	15.9b	92.1ab	49.8ab
2.5 t/ha Rice Straw + 45 kg/ha N	166.4cd	13.9bc	75.7c	51.5bc
5 t/ha Rice Straw + 45 kg/ha N	172.9cd	14.6bc	84.1bc	49.5ab
7.5 t/ha Rice Straw + 45 kg/ha N	179.3bc	15.7b	83.4bc	48.5a
2.5 t/ha Biochar + 90 kg/ha N	188.9ab	17.6a	101.9a	47.8a
5 t/ha Biochar + 90 kg/ha N	190.6ab	18.6a	101.5a	49.3ab
7.5 t/ha Biochar + 90 kg/ha N	196.5a	19.3a	104.1a	47.5a
2.5 t/ha Groundnut Shell + 90 kg/ha N	177.4bc	16.6ab	87.2b	48.5a
5 t/ha Groundnut shell + 90 kg/ha N	179.6bc	17.5a	93.9ab	50abc
7.5 t/ha Groundnut shell + 90 kg/ha N	191.9ab	18.1a	95.5ab	49.8ab
2.5 t/ha Rice Husk + 90 kg/ha N	171.3c	13.2c	77.3c	50.8bc
5 t/ha Rice Husk + 90 kg/ha N	187.1ab	15.5b	91.1b	50.5bc
7.5 t/ha Rice Husk + 90 kg/ha N	193ab	16.6ab	95.7ab	50ab
2.5 t/ha Rice Straw + 90 kg/ha N	178.3bc	13.4c	81.4bc	50abc
5 t/ha Rice Straw + 90 kg/ha N	179.9bc	13.7bc	77.4c	49.5ab
7.5 t/ha Rice Straw + 90 kg/ha N	184.4b	13.6bc	83.3bc	49ab
Grand Mean	171.2	14.8	81.6	50.4
LSD	11.1	3.4	12.6	2.3
CV (%)	4.6	16.3	11	3.2

Figures with the same letters are not significantly different from each other. NB: PH = plant height, LAI = leaf area index, HCA = height of cob attachment and DFF = days to 50% flowe

GRAIN YIELD

Grain yield of maize was enhanced by the combination of residual organic materials and N significantly (p<0.05) with application of 2.5 t/ha Biochar + 90 kg/ha N, 5 t/ha Biochar + 45 - 90 kg/ha N, 7.5 t/ha Biochar + 45 - 90 kg/ha N, 5 t/ha Rice Husk + 45 - 90 kg/ha N, 7.5 t/ha Rice Husk + 45 + 90 kg/ha N and 7.5 t/ha Rice Straw + 90 kg/ha N (Figure 1) below shows the effects of treatments on grain yield at harvest.



Residual organic sources and mineral nitrogen caused significant variation in grain yield of maize. Higher grain yield was observed with the applications of 2.5 t/ha Biochar + 90 kg/ha N, 5 t/ha Biochar + 45 kg/ha N, 5 t/ha Biochar + 90 kg/ha N, 7.5 t/ha Biochar + 45 kg/ha N, 7.5 t/ha Biochar + 90 kg/ha N, 5 t/ha Rice Husk + 45 kg/ha N, 5 t/ha Rice Husk + 90 kg/ha N, 7.5 t/ha Rice Husk + 45 kg/ha N, 7.5 t/ha Rice Husk + 90 kg/ha N, 7.5 t/ha Rice Straw + 90 kg/ha N. Possible explanation for increase in grain yield in organic plots include the residual effect of organic materials on soil physio-chemical properties such as; enhancement of water holding capacity, increased cation exchange capacity (CEC) and providing a medium for adsorption of plant nutrients and improved conditions for soil micro-organisms (Sohi et al., 2009). Organic manure efficiently adsorbs ammonia (NH_3) (Iyobe et al., 2004) and acts as a binder for ammonia in soil, therefore having the potential to decrease ammonia volatilization from soil surfaces. These results are in accordance with Singh et al. (2010) who also observed that timely availability of nitrogen increased corn productivity positively through the increase use of a combination of mineral nitrogen and organic manures. These results are also in line with Boateng et al. (2006) and Ali et al. (2011) who found that corn yield increased by 35% in integrated nitrogen management.

REGRESSION ANALYSIS

The results from multiple regression analysis for mixed models indicated that grain yield (GY) could be determined from the combination of continuous and dummy variables, which accounted for 48.4% of variance in gain yield. The continuous variables included leaf-cover (LC 9) and plant height (Pt ht 9) at 9 WAP and number of days to 50% flowering (50% F), while the dummy variables were 4 best selected treatments including 2.5 t/ha rice straw with 90 kg/ha N, (RS1+Full N), 7.5 t/ha rice straw with 45 kg/ha N (RH3 +1/2 N), 2.5 t/ha groundnut shells with 90 kg/ha N (GS1 + Full N) and 7.5 t/ha Biochar with 90 kg/ha N (BC3 + Full N). Controlling RS1 + Full N, the general prediction model was developed as:

GY = 1409 + 642 (RH3+1/2 N) + 653 (GS1+Full N) + 783 (BC3+Full N) + 168.3 (LC 9) + 16.32 (Pt ht 9) – 82.3 (50% F)...... [Eqn. 3]

Since the treatments were mutually exclusive, the following were the resultant models:

For RH3 + ½ N, GY = 2051 + 168.3 (LC 9) + 16.32 (Pt ht 9) – 82.3 (50% F) .....[Eqn. 3a]

For GS1 + Full N, GY = 2062 + 168.3 (LC 9) + 16.32 (Pt ht 9) – 82.3 (50% F).....[Eqn. 3b]

For BC3 + Full N, GY = 2192 + 168.3 (LC 9) + 16.32 (Pt ht 9) – 82.3 (50% F).....[Eqn. 3c]

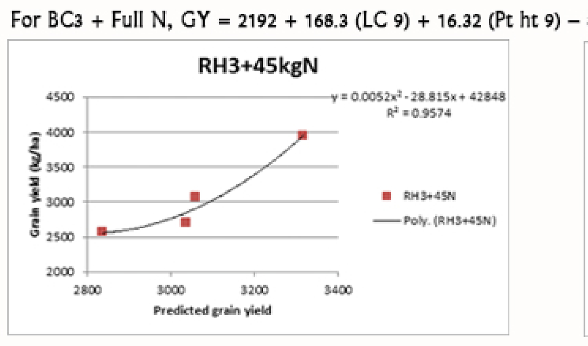


figure 2a: The polynomial for RH3 + 45 kg igure 2a: The

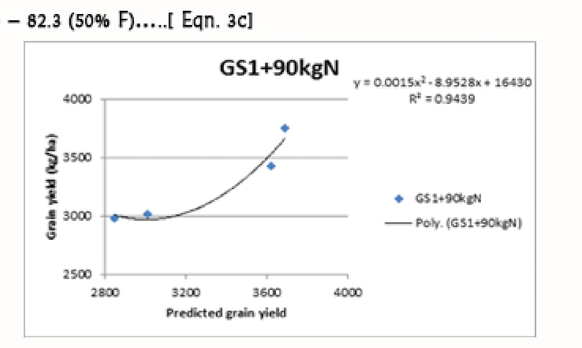


Figure 2b: The polynomial for GS1 + 90 kg

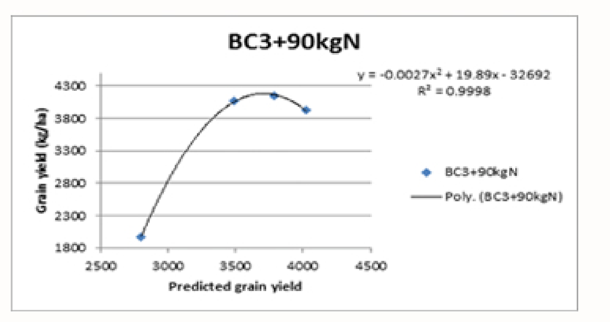


Figure 2c: The polynomial for BC3 + 90 kg N.

CONCLUSION

Results showed increased maize growth and grain production on residual organic material nutrients required supplementary mineral N fertilization. Best growth parameters, early days to 50% flowering and highest cob length, cob weight and stover weight, 100 seed weight and grain yield were obtained with 2.5 to 7.5 t/ha Biochar + 45 - 90 kgN/ha; 5 to 7.5 t/ha Rice Husk + 45 - 90 kgN/ha and 7.5 t/ha Rice Straw + 90 kgN/ha. Biochar provided the least quantitative input of 2.5 t/ha + 45 kgN/ha for maximum maize production and most efficient soil fertility management system. Overall maximum grain yield of maize was attained with 7.5 t/ha Biochar plus 90 kgN/ha as described by Eqn. 3c where grain yield = 2192 + 168.3 (Leaf Count at 9WAS) + 16.32 (Plant height at 9WAS – 82.3 (50% F). However, farmers in the guinea savannah could apply groundnut shell or biochar at 7.5T/ha and 45Kg N/ha to minimize cost and enhance soil fertility and maize production.

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