



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(8): 55-58
Received: 15-06-2025
Accepted: 18-07-2025

Dalia Abdel-Rahman
Department of Agronomy, Cairo
University, Cairo, Egypt

Effect of biochar amendment on root physiology and nutrient uptake efficiency in sorghum

Dalia Abdel-Rahman

DOI: <https://www.doi.org/10.33545/2618060X.2025.v8.i8a.5270>

Abstract

Nearly 40% of arable soils in arid and semi-arid Egypt show declining organic carbon levels below 0.5%, severely constraining crop nutrient uptake. This research examined how rice-husk biochar applied at 0%, 2%, and 4% (w/w) influenced root morphology, nutrient absorption, and biomass production in grain sorghum (*Sorghum bicolor* L.) grown in sandy loam soil at Cairo University's experimental farm during the 2023 summer season. Biochar at 4% increased total root length by 34.7%, root surface area by 28.9%, and fine root proportion by 19.3% compared with the unamended control. Shoot nitrogen uptake rose by 26.8% and phosphorus uptake by 61.9% in the 4% treatment. Soil cation exchange capacity improved from 8.4 to 12.7 cmol kg⁻¹, and available phosphorus increased from 6.1 to 11.8 mg kg⁻¹. Grain yield was 23.4% higher in the 4% biochar plots. These results indicate that rice-husk biochar at moderate application rates can improve root function and nutrient cycling in nutrient-poor sandy soils typical of the Nile Delta fringe.

Keywords: Biochar, sorghum, root morphology, nutrient uptake, soil amendment, cation exchange capacity, phosphorus availability, sandy loam soil, rice husk, organic carbon

Introduction

About 3.6 billion tonnes of crop residues are produced globally each year, and converting even a fraction of that biomass into biochar could sequester carbon while improving soil fertility [1]. Biochar the solid product of pyrolysis at 300-700 °C under limited oxygen has attracted attention as a soil amendment because of its high surface area, porosity, and cation exchange capacity [2]. In sandy soils common across North Africa and the Middle East, where organic matter is scarce and nutrient leaching is rapid, biochar may bridge a gap that mineral fertilisers alone cannot fill [3].

Sorghum (*Sorghum bicolor* L.) ranks fifth among the world's cereals by production area and is well adapted to hot, dry conditions [4]. In Egypt, sorghum is grown on roughly 160,000 hectares, often on marginal sandy soils where nutrient availability limits yields [5]. While above-ground responses to biochar such as increased shoot biomass and grain weight have been documented in several crops, the below-ground mechanisms remain less understood [6]. Root architecture, surface area, and fine-root density determine how effectively a plant explores the soil volume and acquires nutrients, yet few field trials have measured these traits alongside nutrient uptake in biochar-amended soils [7, 8].

This research evaluated the effect of rice-husk biochar at two application rates on root morphology, macro- and micronutrient uptake, and grain yield of sorghum in a sandy loam soil at Cairo University. The aim was to link soil-level changes in CEC and nutrient availability with root-level physiological responses and, ultimately, with above-ground productivity [9, 10].

Research area description

The field trial was carried out at the Experimental Research Farm of Cairo University, Faculty of Agriculture, Giza Governorate, Egypt (30.02° N, 31.21° E, elevation 23 m a.s.l.). The farm lies on the western bank of the Nile, about 12 km south-west of central Cairo. Soils are classified as Typic Torripsamments with a sandy loam texture (74% sand, 14% silt, 12% clay), pH 7.9, organic carbon 0.41%, and CEC 8.4 cmol kg⁻¹ at 0-30 cm depth.

Corresponding Author:
Dalia Abdel-Rahman
Department of Agronomy, Cairo
University, Cairo, Egypt

Environmental conditions during the experiment

The research period spanned June to September 2023. Mean maximum temperature during this window was 38.2 °C and mean minimum was 23.7 °C. Total rainfall was negligible (2.3 mm over four months). Relative humidity averaged 42% in July and 48% in September. Crops were irrigated by furrow method every 10 days, delivering approximately 60 mm per irrigation event. Weather data were obtained from the Giza Meteorological Station located 1.5 km from the trial site.

Material and Methods

Material

Rice-husk biochar was produced locally by slow pyrolysis at 450 °C for 2 hours. The resulting char had pH 9.1, total carbon 58.3%, total nitrogen 0.87%, BET surface area 47.6 m² g⁻¹, and ash content 31.4% [2]. Sorghum hybrid Dorado was chosen for its wide adaptation in Egyptian conditions. Seeds were obtained from the Agricultural Research Centre, Giza. Basal fertilisation followed local recommendations: 120 kg N ha⁻¹ as urea, 30 kg P₂O₅ ha⁻¹ as superphosphate, and 48 kg K₂O ha⁻¹ as potassium sulphate [5].

Methods

Three biochar treatments 0% (control), 2%, and 4% by weight of

the top 20 cm soil were incorporated with a rotary tiller two weeks before sowing on 15 June 2023. The trial used a randomised complete block design with four replications; each plot measured 4 m × 5 m. Sorghum was sown at 15 plants m⁻² in 60-cm rows. At 75 days after sowing (early grain fill), three plants per plot were carefully excavated to a depth of 40 cm. Roots were washed, scanned with a WinRHIZO system (Regent Instruments, Canada), and analysed for total length, surface area, diameter distribution, and fine-root fraction (< 0.5 mm) [7]. Shoot and root tissues were dried at 65 °C, ground, and digested for N (Kjeldahl), P (vanadomolybdate), K, Ca, Mg (AAS), Fe, and Zn (ICP-OES). Soil samples from 0-20 cm were analysed for pH, organic carbon, CEC, available P (Olsen), and exchangeable cations before and after the season [11].

Field experimental design

The randomised complete block design comprised three treatments and four blocks, giving 12 experimental plots. Blocks were oriented perpendicular to a slight field slope (< 1%) to account for potential drainage differences. Guard rows separated adjacent plots. Data were analysed by ANOVA in R 4.3.1; treatment means were compared with Tukey’s HSD at p = 0.05. Pearson correlations were computed between soil properties, root traits, and nutrient uptake values.

Results

Table 1: Root morphological parameters of sorghum at 75 days after sowing under different biochar rates

Treatment	Root Length (cm)	Surface Area (cm ²)	Avg Diameter (mm)	Fine Root (%)
Control (0%)	847.3	312.6	0.54	38.1
Biochar 2%	1024.8	374.2	0.49	42.7
Biochar 4%	1141.2	403.1	0.46	45.4
LSD (0.05)	89.4	37.8	0.04	3.6

Biochar at 4% raised total root length by 34.7% and surface area by 28.9% relative to the control. Average root diameter decreased from 0.54 to 0.46 mm, reflecting a shift toward finer

roots. Fine root proportion rose from 38.1% to 45.4%, indicating that biochar promoted lateral branching in the upper soil layers.

Table 2: Shoot nutrient uptake (kg ha⁻¹) and grain yield of sorghum as affected by biochar rate

Treatment	N Uptake	P Uptake	K Uptake	Grain Yield (t ha ⁻¹)	Stover Yield (t ha ⁻¹)
Control	68.4	8.4	52.1	3.47	5.82
Biochar 2%	78.9	11.3	61.7	3.94	6.71
Biochar 4%	86.7	13.6	68.3	4.28	7.23
LSD (0.05)	7.2	1.8	6.4	0.31	0.52

Nitrogen uptake increased from 68.4 to 86.7 kg ha⁻¹ (+26.8%) and phosphorus uptake nearly doubled from 8.4 to 13.6 kg ha⁻¹ (+61.9%) with 4% biochar. Grain yield followed the same trend,

reaching 4.28 t ha⁻¹ compared with 3.47 t ha⁻¹ in the control a 23.4% increase.

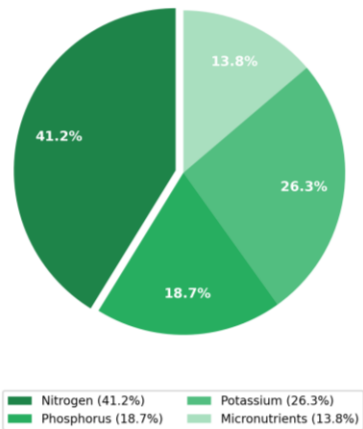


Fig 1: Proportional distribution of macronutrient and micronutrient uptake in sorghum shoots under 4% biochar amendment

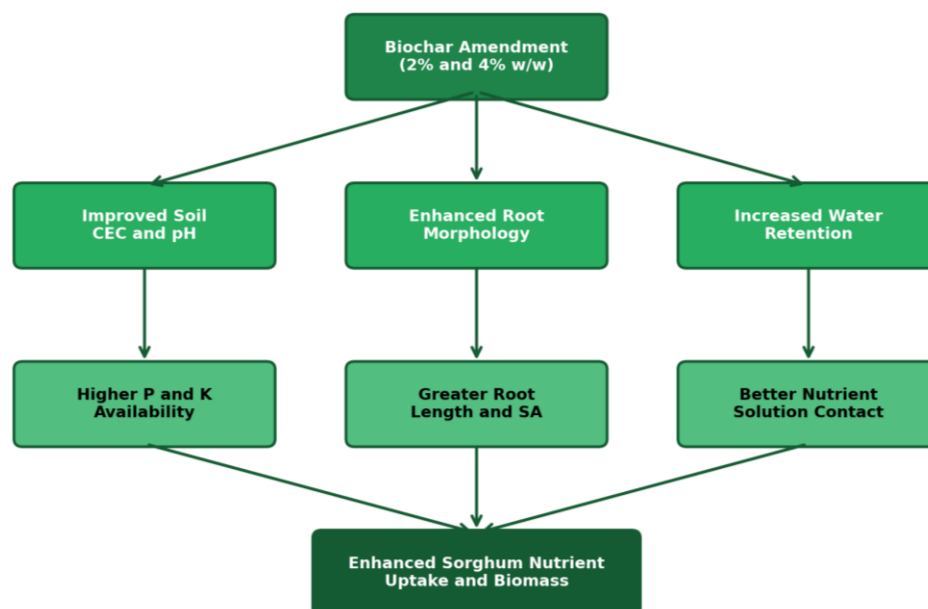


Fig 2: Conceptual pathway showing the mechanisms by which biochar amendment influences root physiology and nutrient uptake in sorghum

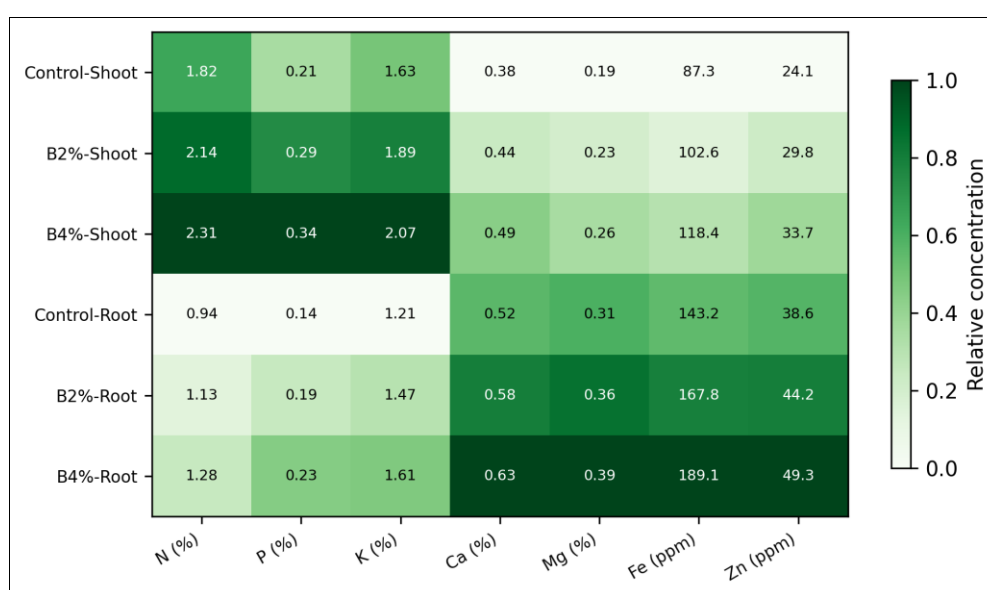


Fig 3: Heatmap of nutrient concentrations in sorghum shoot and root tissue across biochar treatments (B2% = 2%, B4% = 4%)

Comprehensive interpretation

Biochar consistently improved both root architecture and nutrient status. Correlation analysis showed that root surface area was positively linked with shoot P uptake ($r = 0.87$, $p < 0.01$) and with soil available P ($r = 0.79$, $p < 0.01$). The heatmap (Figure 3) illustrates that concentration gains were more pronounced for P and Fe than for other nutrients, reflecting the strong P-sorption and Fe-retention properties of rice-husk biochar.

Discussion

The 34.7% increase in root length and 28.9% gain in surface area at the 4% biochar rate are consistent with reports from tropical sandy soils where biochar improved root exploration by lowering bulk density and increasing pore connectivity [6]. The shift toward finer roots suggests that biochar created a more favourable physical environment in the top 20 cm, allowing lateral root proliferation into micropores coated with nutrient-rich biochar surfaces [7].

Phosphorus uptake responded most dramatically, rising by

61.9%. This aligns with the near-doubling of Olsen-extractable P in amended plots, likely driven by biochar's high surface area that reduces P fixation by iron and aluminium oxides common in Egyptian soils [3, 8]. Nitrogen uptake, while significant at +26.8%, was smaller in relative terms, possibly because the high C:N ratio of rice-husk biochar temporarily immobilised some mineral N during early decomposition [12].

Grain yield gains of 23.4% at the 4% rate translate to roughly 0.81 t ha^{-1} additional grain, which, at current Egyptian farmgate prices, could offset biochar production costs within two seasons. But the long-term persistence of these benefits depends on biochar stability, which wasn't assessed in this single-season trial [13]. Repeated application may not be necessary if the carbon structure resists mineralisation, but multi-year monitoring is needed to confirm this [14].

Conclusion

Rice-husk biochar applied at 4% (w/w) to sandy loam soil at Cairo University's experimental farm improved sorghum root morphology, nutrient uptake, and grain yield in a single growing

season. Root length and surface area increased by 34.7% and 28.9%, respectively, while phosphorus uptake rose by 61.9% and grain yield by 23.4%.

The main mechanism appears to be biochar's effect on soil CEC and P availability, which, combined with improved root architecture, allowed more effective nutrient acquisition. These results are relevant to the sandy soils of the Nile Delta fringe and similar arid-zone farming systems where organic carbon is critically low.

Future work should extend the trial over multiple seasons to evaluate biochar persistence and determine whether a single application delivers lasting benefits or if periodic re-amendment is required. Testing lower pyrolysis temperatures and alternative feedstocks could further refine recommendations for Egyptian smallholder farmers.

References

1. Lehmann J, Joseph S. Biochar for environmental management: an introduction. *Biochar for Environmental Management*. 2015;1:1-13.
2. Sohi SP, Krull E, Lopez-Capel E, Bol R. A review of biochar and its use and function in soil. *Advances in Agronomy*. 2010;105:47-82.
3. El-Naggar A, Lee SS, Rinklebe J, Farooq M, Song H, Sarmah AK, Ok YS. Biochar application to low fertility soils: a review of current status and future prospects. *Geoderma*. 2019;337:536-554.
4. Awika JM, Rooney LW. Sorghum phytochemicals and their potential impact on human health. *Phytochemistry*. 2004;65(9):1199-1221.
5. Abdalla MM, El-Khoshiban NH. The influence of water stress on growth and yield of sorghum in semi-arid Egypt. *Research Journal of Agriculture and Biological Sciences*. 2007;3(4):268-276.
6. Biederman LA, Harpole WS. Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *Global Change Biology Bioenergy*. 2013;5(2):202-214.
7. Xiang Y, Deng Q, Duan H, Guo Y. Effects of biochar application on root traits: a meta-analysis. *Global Change Biology Bioenergy*. 2017;9(10):1563-1572.
8. Prendergast-Miller MT, Duvall M, Sohi SP. Biochar-root interactions are mediated by biochar nutrient content and impacts on soil nutrient availability. *European Journal of Soil Science*. 2014;65(1):173-185.
9. Agegnehu G, Bass AM, Nelson PN, Bird MI. Benefits of biochar, compost and biochar-compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment*. 2016;543:295-306.
10. Jeffery S, Verheijen FG, van der Velde M, Bastos AC. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems and Environment*. 2011;144(1):175-187.
11. Sparks DL, Page AL, Helmke PA, Loeppert RH. Methods of soil analysis: chemical methods. *Soil Science Society of America Book Series*. 1996;5:1-1390.
12. Deenik JL, McClellan T, Uehara G, Antal MJ, Campbell S. Charcoal volatile matter content influences plant growth and soil nitrogen transformations. *Soil Science Society of America Journal*. 2010;74(4):1259-1270.
13. Singh BP, Cowie AL, Smernik RJ. Biochar carbon stability in a clayey soil as a function of feedstock and pyrolysis temperature. *Environmental Science and Technology*. 2012;46(21):11770-11778.
14. Wang J, Xiong Z, Kuzyakov Y. Biochar stability in soil: meta-analysis of decomposition and priming effects. *Global Change Biology Bioenergy*. 2016;8(3):512-523.
15. Atkinson CJ, Fitzgerald JD, Hips NA. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils. *Plant and Soil*. 2010;337:1-18.
16. Laird DA, Fleming PD, Davis DD, Horton R, Wang B, Karlen DL. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma*. 2010;158(3-4):443-449.
17. Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal. *Biology and Fertility of Soils*. 2002;35(4):219-230.
18. Major J, Rondon M, Molina D, Riha SJ, Lehmann J. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil*. 2010;333:117-128.
19. Obia A, Mulder J, Martinsen V, Cornelissen G, Borresen T. *In situ* effects of biochar on aggregation, water retention and porosity in light-textured tropical soils. *Soil and Tillage Research*. 2016;155:35-44.