Original Research

Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in

Journal of Environmental Biology

JEB™ p-ISSN: 0254-8704
e-ISSN: 2394-0379
CODEN: JEBIDP

DOI : http://doi.org/10.22438/jeb/40/5/MRN-1052

Tolerance evaluation of *Jatropha curcas* and *Acacia burkei* to acidic and copper/nickel-contaminated soil

Paper received: 21.11.2018 *Revised received*: 27.03.2019 *Re-revised received*: 29.04.2019 *Accepted*: 08.05.2019

Authors Info

T. Konaka[1], Y. Ishimoto[2], M. Yamada[3], B. Moseki[4], H. Tsujimoto[1,3,5], C. Mazereku[6] and K. Akashi[1,3,5]*

[1]United Graduate School of Agricultural Sciences, Tottori University, Tottori-680 8553, Japan

[2]Aomori Public University, Aomori, 030-0196, Japan

[3]Graduate School of Sustainability Science, Tottori University, Tottori-680 8553, Japan

[4]Department of Biological Sciences, University of Botswana, UB 00704, Gaborone, Botswana

[5]Arid Land Research Center, Tottori University, Tottori, 680-0001, Japan

[6]Department of Agricultural Research, Ministry of Agriculture, Botswana, 0033, Gaborone, Botswana

***Corresponding Author Email :** akashi.kinya@tottori-u.ac.jp

Edited by

Dr. R.B. Raizada

Reviewed by

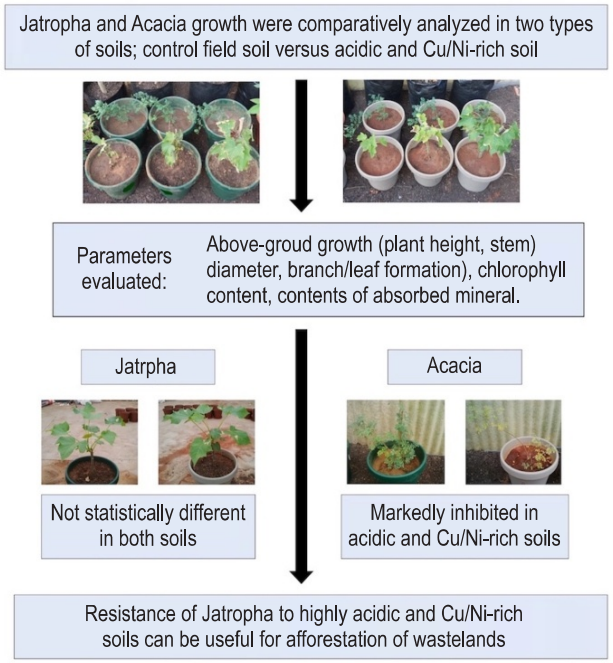
Dr. Subhash Babu
Prof. Vikash Abrol

Abstract

Aim : To evaluate tolerance of two tree species, *Jatropha curcas* and *Acacia burkei*, to an acidic and highly Cu/Ni-contaminated soil.

Methodology : Above-ground growth of *Jatropha* and *Acacia* were monitored for six months in two different soil types; a typical field soil (FS) and acidic and Cu/Ni-rich soil (ACNS), the latter containing 58- and 14-fold higher levels of Cu and Ni, respectively, than FS.

Results : Growth of Acacia was markedly inhibited in ACNS, as evidenced by low number of petioles and branches, thinner stem diameter, and low chlorophyll content compared with plants grown in FS. In contrast, tree height, stem diameter and length of emerged branches of Jatropha showed no significant differences between growth in FS and ACNS. In Jatropha, foliar Cu content grown in ACNS was not statistically different from that in FS whereas a small increase in foliar Ni content was observed in ACNS.



Interpretation : These observations suggested that Jatropha possess strong resistance to acidic and Cu/Ni-enriched soil. This trait might be advantageous for dual-purpose, utilization of Jatropha for renewable energy production and afforestation of Cu/Ni-polluted wastelands.

Key words: *Acacia burkei*, Acidic soil, Arid region, *Jatropha curcas*

How to cite : Konaka, T., Y. Ishimoto, M. Yamada, B. Moseki, H. Tsujimoto, C. Mazereku and K. Akashi : Tolerance evaluation of *Jatropha curcas* and *Acacia burkei* to acidic and copper/nickel-contaminated soil. *J. Environ. Biol.*, **40**, 1109-1114 (2019). **DOI :** http://doi.org/10.22438/jeb/40/5/MRN-1052

Introduction

Jatropha curcas (Jatropha) belongs to family Euphorbiaceae and contains 25%–38% (w/w) oil in their seeds (Wani *et al.,* 2012b) which can be converted to biodiesel. Jatropha has gained attention as a source of renewable energy (Parawira, 2010; Montes and Melchinger, 2016). The potential of mitigation of greenhouse gas emissions has been discussed (van Eijck *et al.,* 2014; Ishimoto *et al.,* 2018). In addition, the use of Jatropha non-oil biomass as a feedstock for organic fertilizer, soil conditioner (Abdul Khalil *et al.,* 2013; Ogura *et al.,* 2016), and renewable energy has also been reported (Jingura *et al.,* 2010). Although several issues, such as oil production cost and the need for improved yield, have been highlighted for Jatropha-based bioenergy production (Borman *et al.,* 2013), Jatropha is considered a suitable plant for sustainable energy production, especially for rural communities (Wicke *et al.,* 2011). Jatropha is a drought tolerant plant (Quinn *et al.,* 2015), that can thrive in semi-arid conditions and can survive even on degraded lands (Pandey *et al.,* 2012). Moreover, in a previous study it has been reported that Jatropha deposits significant amount of carbon in soil (Wani *et al.,* 2012a). These characteristics suggest that Jatropha can be an attractive tree for afforestation of otherwise unused wastelands.

The possibility of phytoremediation of potential toxic element (PTE)-contaminated lands using Jatropha has been suggested in previous studies (Agamuthu *et al.,* 2010; Ghavri and Singh, 2012; Chang *et al.,* 2014). Majid *et al.* (2012) studied the bio accumulation of copper, lead and zinc in Jatropha grown in a sawdust-contaminated soil. Abdullahi *et al.* (2017) demonstrated the potential of Jatropha for reclamation of soils polluted by zinc, copper and cadmium. Using stem cuttings, Ghavri and Singh (2012) reported copper accumulation in the roots of Jatropha grown in a contaminated soil. No decrease in shoot and root dry weight was observed in Jatropha grown in PTE-containing magnesite and bauxite mine soils as compared to control soil (Mathiyazhagan and Natarajan, 2012). These reports suggested that Jatropha might be tolerant to a wide range of PTEs. In Botswana, an area with high acidic and Cu/Ni-enriched soil has been reported in the vicinity of a Cu/Ni mining industrial site (Vurayai *et al.,* 2015), which has adversely affected the vegetation of that area. It is hypothesized that Jatropha might be more resistant to Cu/Ni-rich soil as compared to ordinary tree species such as *Acacia burkei* (Acacia),which is one of the dominant tree species in African savanna (Masia *et al.,* 2018) and adapts well to the climatological conditions of Botswana (van Wyk and van Wyk, 2013). In view of the above, this study was conducted to investigate the growth performance of *Jatropha* and *Acacia* in high acidic and Cu/Ni-rich soil.

Materials and Methods

Experimental soils: Two different soils were used in this experiment. One was collected from a field located approximately 4 km north-east the Department of Agricultural Research (DAR), Ministry of Agriculture in Sebele, Gaborone, Botswana, that was used for Jatropha cultivation (Inafuku-Teramoto *et al.,* 2013). This soil was designated as field soil (FS). The other soil was collected from the area around Cu/Ni mining site in Selebi-Phikwe, in the central district of Botswana. This soil was designated as acidic and Cu/Ni-rich soil (ACNS). The soil pH values were analyzed using an inoLab pH 720 meter (WTW GmbH, Weiheim, Germany). Organic carbon content in the soils were measured by potassium dichromate method with a spectrophotometer (UVD2950, Labomed, Los Angeles, CA, USA). For mineral analyses, soils were digested by the following method. Soil samples were dried at 70°C for two days. Dried soil samples (0.2 g) were ground using a mortar and pestle, and then 10 ml of concentrated HNO_3 was added and the mixtures were boiled until a final volume of 3 ml was reached. Subsequently, 10 ml of concentrated HCl was added, and the mixtures were evaporated to a volume of 3 ml. After filtration, the solutions were diluted to 40 ml with distilled water. The resultant decomposed materials were dissolved in 1% HNO_3, and their mineral contents were analyzed using inductively coupled plasma atomic emission spectroscopy (ICP-AES; SPECTRO CIROS CCD, SPECTRO Analytical Instruments GmbH, Nordrhein-Westfalen, Germany).

Plant materials and monitoring of growth: The branches of *Jatropha curcas* were collected from the trees at the Department of Water Affairs of the Ministry of Mineral Resources, Green Technology and Energy Security in Gaborone, Botswana. The branches were cut to approximately 15 cm long, and planted into a commercially-available horticultural organic soil for potting culture (Potting Soil, New Frontiers, Lobatse, Botswana) in 5 l polyethylene bags in a greenhouse at DAR. Approximately, 1 month after planting, sprouted Jatropha cuttings with a stem diameter of approximately 5 mm, 5 cm above ground level were used in this study. Seeds of *Acacia burkei* were collected from a mother tree on Block 8, Gaborone, Botswana, and germinated in the horticulture soil in a greenhouse at DAR. Acacia seedlings of approximately 10 cm long and 3 mm stem diameter, 5 cm from ground level were used in this study.

Three replicates of juvenile plants of *Jatropha* and *Acacia* were carefully transplanted into pots filled with 10 kg of experimental soils of FS or ACNS, and grown in a greenhouse at DAR. Approximately, one litre of water per pot was applied once a week; no fertilizers were applied during the study. Six months after transplantation, growth parameters such as plant height and stem diameter at a height of 5 cm above ground level were measured for all plants. For Acacia trees, the total numbers of first-and second-order branches (Ickert-Bond *et al.,* 2015), and the total number of petioles per tree were counted. For Jatropha, the length of newly sprouted primary branch and total number of leaves on each tree were measured. Chlorophyll contents in the fully-expanded upper leaves was estimated following the method of (Han *et al.,* 2018), with minor modification. The optical absorbance of the supernatant was measured at wavelengths of 645, 663, and 720 nm using a Ce2041 spectrophotometer (Cecil Instruments, Peterborough, UK), and used for the calculation of

the chlorophyll content (Porra *et al.,* 1989). For the estimation of nutrient minerals and PTEs in Jatropha leaves, approximately 200 mg dried leaves were dissolved in 10 ml concentrated HNO_3 in a flask, and digested on a hot plate at 240°C until the volume was reduced to 1 ml. The solutions were diluted to 25 ml with 1% HNO_3 and the mineral contents were measured using ICP-AES as described above.The enrichment factor of minerals and PTEs in the leaves was calculated by the following equation: EF = $[element]_{leaf}$ / $[element]_{soil}$ (Zu *et al.,* 2005). Statistical significance of difference was evaluated by t-test using Microsoft Excel.

Results and Discussion

The major chemical components of two soils used in this study, FS and ACNS, are shown in Table 1. The pH of field soil was 4.92, and its organic carbon content was 0.31%. The five major mineral elements found in the FS were aluminum, iron, calcium, manganese and titanium. In contrast, the pH of ACNS was 3.39, revealing highly acidic nature of this soil. The organic carbon content of ACNS was 0.12%, which was lower than that of FS. Mineral contents in ACNS were mostly within the range of 5-fold differences when compared with those in FS, except for Cu, Ni, and Ti, which were 58-, 14-, and 8.9-fold higher, than those in FS. Notably, Cu (604 mg kg^{-1}) and Ni (365 mg kg^{-1}) levels in the ACNS were markedly higher than those in a previous report (Chang *et al.,* 2014), where Jatropha was used for phytoremediation of a PTE-contaminated field (Cu: 23.07 mg kg^{-1} and Ni: 20.99 mg kg^{-1}).

Growth of Acacia was adversely affected in ACNS as compared to FS (Table 2). The number of petioles on ACNS-grown plants was 11.7 per tree, which was only 14% of FS (82.7). The total number of first-and second-order branches was also significantly reduced in ACNS. In ACNS, plants had two branches per tree, as compared to five branches per tree in field soil. Although tree height was not significantly different between the two conditions, stem diameter 5 cm above ground level in ACNS was 10.3 mm, which was 26% thinner than FS (14.0 mm). In ACNS, the chlorophyll content of fully expanded petiolate leaves on the upper part of tree was 2.17 µg chl cm^{-2}, which was significantly lower than that in FS (7.21 µg chl cm^{-2}). These results suggested that growth of Acacia was inhibited by acidic and Cu/Ni-rich soils. The detailed inhibitory mechanisms of Acacia trees in such soils should be examined in future studies.

In contrast, Jatropha trees grown in ACNS and FS showed no remarkable morphological differences. The height of Jatropha trees in ACNS was 25 cm, which was statistically insignificant from that in FS (24.3 cm; Table 2). Stem diameter 5 cm above ground level was 16.0 mm in ACNS, which was similar to that in FS (14.7 mm). In both conditions, only a single new

Table 1 : The pH, organic carbon and mineral contents in the experimental soils used in this study

	Soil			
	FS[*1]	ACNS[*2]	p-value[*3]	Fold difference[*4]
pH	4.92	3.39		
Organic carbon (%)	0.31	0.12		
Mineral content (mg kg^{-1} soil)[*5]				
Al	40,100 ± 300	52,700 ± 1,100	2.9×10^{-4}	1.3
Ca	5,880 ± 40	19,300 ± 100	2.1×10^{-9}	3.3
Cd	3.42 ± 0.05	5.21 ± 0.04	3.2×10^{-5}	1.5
Co	78.6 ± 2.2	151 ± 1	2.8×10^{-5}	1.9
Cr	67.5 ± 0.5	52.4 ± 0.6	7.9×10^{-5}	0.78
Cu	10.5 ± 0.2	604 ± 3	9.1×10^{-8}	58
Fe	13,100 ± 100	28,900 ± 200	8.3×10^{-7}	2.2
K	299 ± 2	578 ± 2	8.1×10^{-7}	1.9
Mg	25.4 ± 0.3	90.4 ± 0.1	1.3×10^{-7}	3.6
Mn	704 ± 7	125 ± 1	1.7×10^{-6}	0.18
Ni	25.2 ± 0.3	365 ± 5	3.4×10^{-6}	14
P	136 ± 2	241 ± 2	1.1×10^{-5}	1.8
Pb	61.3 ± 0.8	61.0 ± 0.5	0.57	n.a.[*6]
Sn	19.6 ± 0.8	23.6 ± 0.9	1.3×10^{-2}	1.2
Ti	334 ± 3	2,960 ± 50	1.8×10^{-6}	8.9
Zn	19.6 ± 0.1	60.9 ± 0.6	2.5×10^{-6}	3.1

[*1] FS: field soil; [*2] ACNS: acidic and Cu/Ni-rich soil; [*3] The probability values for the significant difference between the two soils were calculated by t-test($p < 0.05$); [*4] Fold difference of the value for ACNS in comparison to that of FS; [*5] Values are the average and standard deviation (n = 2~3) and [*6] n.a.: not applicable because the difference was not statistically significant

Table 2 : Growth data on Acacia and Jatropha plants grown in FS and ACNS after six months

Growth parameters	Acacia[*1]				Jatropha[*1]			
	FS[*2]	ACNS[*3]	p-value[*4]	Fold[*5]	FS[*2]	ACNS[*3]	p-value[*4]	Fold[*5]
Height (cm)	28.3 ± 6.0	31.0 ± 10.4	0.72	n.a.[*6]	24.3 ± 8.7	25.0 ± 7.0	0.92	n.a.[*6]
Diameter (mm)	14.0 ± 1.0	10.3 ± 0.6	5.3×10^{-3}	0.74	14.7 ± 0.6	16.0 ± 1.0	0.12	n.a.[*6]
Number of petioles per tree	82.7 ± 4.7	11.7 ± 5.0	5.8×10^{-5}	0.14	n.d.[*7]	n.d.[*7]	n.d.[*7]	n.d.[*7]
Number of branches per tree	5.0 ± 0.0	2.0 ± 1.0	6.5×10^{-3}	0.40	1.0 ± 0.0	1.0 ± 0.0	1.0	1.0
Total length of emerged branch	n.d.[*7]	n.d.[*7]	n.d.[*7]	n.d.[*7]	45.0 ± 21.8	56.7 ± 55.1	0.75	n.a.
Number of leaves per tree	n.d.[*7]	n.d.[*7]	n.d.[*7]	n.d.[*7]	5.3 ± 2.9	10.3 ± 1.2	4.9×10^{-2}	1.9

[*1] Values are mean ±SD (n = 3); [*2] FS: Field soil; [*3] ACNS: Acidic and Cu/Ni-rich soil; [*4] Probability values for significant difference between the two soils were calculated by t-test ($p < 0.05$); [*5] Fold difference of the value for ACNS as compared to FS; [*6] n.a.: not applicable as the difference was not statistically in significant and [*7] n.d.: not determined

branch emerged from the original cutting for a given plant. The length of the emerged branch was 56.7 and 45.0 mm in ACNS and FS, respectively, showing that the values were highly variable and statistically indifferent between the two conditions. Of note, the number of leaves on Jatropha grown on ACNS (10.3) were more than those grown on FS (5.3). The reason for higher number of leaves in ACNS is currently unknown. The chlorophyll content of Jatropha leaves in ACNS was 10.2 µg chl cm^{-2}, which was not significantly different from those of FS (11.4 µg chl cm^{-2}). Although the growth characteristics of Jatropha in the acidic and Cu/Ni-enriched soils awaits further evaluation in long term natural field conditions, the present results demonstrate that vegetative growth of Jatropha might not be negatively influenced by ACNS. The observed tolerance of Jatropha to Cu/Ni-enriched soils suggest that afforestation of Jatropha may serve as a measure for remediating Cu/Ni-polluted wastelands.

Table 3 : Contents and enrichment factors for the nutrient minerals and potentially toxic elements in Jatropha leaves

Mineral	FS[*1]		ACNS[*2]		p-value[*5]	Fold difference[*6]
	Content (mg kg^{-1})[*3]	EF[*4]	Content (mg kg^{-1})[*3]	EF[*4]		
Al	341 ± 200	8.5×10^{-3}	503 ± 372	9.5×10^{-3}	0.51	n.a.[*7]
Ca	5,120 ± 1,780	0.87	8,110 ± 7,670	0.42	0.54	n.a.
Cd	< 0.1	n.a.	< 0.1	n.a.	n.a.	n.a.
Co	3.52 ± 0.18	4.5×10^{-2}	4.27 ± 0.36	2.8×10^{-2}	7.7×10^{-2}	n.a.
Cr	2.31 ± 0.60	3.4×10^{-2}	1.93 ± 1.46	3.7×10^{-2}	0.69	n.a.
Cu	3.90 ± 0.17	0.37	3.67 ± 1.16	6.1×10^{-3}	0.81	n.a.
Fe	57.8 ± 19.1	4.4×10^{-3}	79.1 ± 63.7	2.7×10^{-3}	0.60	n.a.
K	9,180 ± 6,860	31	4,600 ± 3,530	8.0	0.21	n.a.
Mg	1,870 ± 2,430	74	1,860 ± 960	21	0.99	n.a.
Mn	48.0 ± 5.3	6.8×10^{-2}	64.7 ± 37.1	0.52	0.48	n.a.
Ni	1.84 ± 1.28	7.3×10^{-2}	5.55 ± 2.34	1.5×10^{-2}	4.1×10^{-2}	3.0
P	6,270 ± 1,500	46	5,190 ± 610	21	0.15	n.a.
Pb	2.54 ± 1.45	4.1×10^{-2}	2.85 ± 2.03	4.7×10^{-2}	0.83	n.a.
Sn	4.95 ± 1.02	0.25	4.79 ± 1.48	0.20	0.87	n.a.
Ti	1.10 ± 0.10	3.3×10^{-3}	2.76 ± 0.05	9.3×10^{-4}	1.1×10^{-4}	2.5
Zn	35.5 ± 11.0	1.8	37.3 ± 10.5	0.61	0.82	n.a.

[*1] FS: field soil; [*2] ACNS: acidic and Cu/Ni-rich soil; [*3] Values are mean ±SD (n = 2~6); [*4] EF: Enrichment factor, [Elements]leaf / [Elements]soil; [*5] Probability values for significant difference between the content of two soils were calculated by t-test ($p < 0.05$); [*6] Fold difference of the value of content for ACNS as compared to FS and [*7] n.a.: not applicable as the difference was statistically in significant

The observed tolerance of Jatropha to ACNS, which was rich in Cu, Ni and Ti, prompted us to examine the foliar accumulation of these PTEs in Jatropha. The nutritive minerals and PTEs in Jatropha leaves revealed that the foliar contents of most elements were not statistically different between the plants grown in FS and ACNS, except for Ni and Ti (Table 3). The foliar Ni and Ti contents were 3- and 2.5-fold larger in ACNS (5.55 and 2.76 mg kg^{-1} for Ni and Ti as compared to FS (1.84 and 1.10 mg kg^{-1} for Ni and Ti). The observed fold differences were smaller than fold differences of soil Ni/Ti contents between ACNS and FS (14- and 8.9-fold higher Ni and Ti contents, Table 1). The enrichment factors (EFs) of Ni and Ti in ACNS, which reflect the fold-increase in foliar mineral content in comparison with that of soil, was only 1.5×10^{-2} and 9.3×10^{-4} for Ni and Ti, respectively (Table 3). This observation suggeste that excess Ni and Ti in ACNS may be inefficiently absorbed by Jatropha roots, or may be inefficiently translocated to leaf tissues. Ni is an essential mineral nutrient for plant growth and plays a crucial role in certain enzymes such as urease, however, excess Ni cause cellular injuries and plant death (Yusuf *et al.,* 2011). Whereas Ti is non essential for plant growth, however, positive effects of adequate concentration of soil Ti on plant growth and phytotoxicity due to excess Ti has been reported (Lyu *et al.,* 2017). The results of this study revealed that Jatropha did not hyperaccumulate these toxic metals in the leaf tissue. Rather, resistance in Jatropha may be an excluder strategy (Baker, 1981), which limits the accumulation of excess amount of toxic metals in leaves.

Notably, foliar Cu content in Jatropha grown in ACNS (3.67 mg kg^{-1}) was not statistically different from plants grown in FS (3.90 mg kg^{-1}; Table 3), showing that the foliar Cu contents were maintained at similar levels regardless of a large difference in the soil Cu content (58-fold higher in ACNS than in FS; Table 1). This observation suggested that foliar Cu homeostasis in Jatropha might be more strictly controlled than those of Ni and Ti in this study. Cu is a cofactor of many enzymes and play essential roles in various biological processes, such as iron mobilization for normal growth and development (Festa and Thiele, 2011). However, high level of Cu in soils can be phytotoxic (Nagajyoti *et al.,* 2010). Being one of the essential transition metals, Cu has unique redox-active properties to potentially enhance formation of reactive oxygen species (Shahid *et al.,* 2014). Observed stability of Cu content in Jatropha leaves in this study may therefore indicate a mechanism of strict control for Cu homeostasis to avoid Cu-induced damage.

Previous studies have reported that Jatropha concentrated more Cu in their roots than leaves (Ghavri and Singh, 2012; Majid *et al.,* 2012; Chang *et al.,* 2014). In another study, Jatropha leaves and stems accumulated more Cu than their roots (Abdullahi *et al.,* 2017). These previous reports, together with the present observations, suggested that the response of Jatropha to Cu-enriched soils might be variable, possibly influenced by multiple factors such as soil physico-chemical properties, Jatropha physiology and its underlying genetic varieties, and a combination there of.

Of note, the EF of essential minerals such as potassium, magnesium and phosphorus, showed high values in ACNS (Table 3), which were in striking contrast to the behavior of PTEs. This observation suggested that Jatropha selectively translocated nutrient minerals for growth whereas translocation of PTEs from soil to foliar tissues was effectively suppressed.

In summary, this study showed that Jatropha can grow in highly acidic and Cu/Ni-rich soils, and its growth was similar to that in control soil. This trait was different from the growth characteristics of Acacia, which showed severe growth retardation in the acidic and Cu/Ni-rich soil. Analysis of mineral composition in Jatropha leaves showed a slight increase in the foliar Ni content in Cu/Ni-rich soil whereas foliar Cu contents were not statistically different between Cu/Ni-rich and control soil, suggesting that translocation of these PTEs to leaves, particularly for Cu, might be effectively suppressed in Jatropha. These observations highlighted potent resistance of Jatropha to acidic and Cu/Ni-enriched soil, which may be advantageous for the utilization of Jatropha for afforestation of Cu/Ni-polluted wastelands.

Acknowledgments

The authors thank all the participants of the project "Information-based optimization of Jatropha biomass energy production in the frost- and drought-prone regions of Botswana", under the SATREPS program of Japan International Cooperation Agency (JICA), Japan Science and Technology Agency (JST), and the Government of Botswana, for their useful advice. Authors especially thank Dr. Yasuhiro Date, Dr. Jun Tominaga, Dr. Derick George, and Mr. Katso Lethola, for their technical assistance in this study. We thank Dr. Catherine Dandie from Edanz Group (www.edanzediting.com/ac) for editing a draft of this manuscript.The authors acknowledge financial supports from the Joint Research Program and the Project Marginal Region Agriculture from the Arid Land Research Center, Tottori University, the IPDRE Program from Tottori University, and the SATREPS program from JICA, JST and the Government of Botswana.

References

Abdul Khalil, H.P.S., N.A. Sri Aprilia, A.H. Bhat, M. Jawaid, M.T. Paridah and D. Rudi: A Jatropha biomass as renewable materials for biocomposites and its applications. *Renew. Sustain. Energy Rev.,* **22**, 667–685 (2013).

Abdullahi, Z., A.A. Audu and S. Bala: Assessment of the phytoremediation potentials of *Jatropha curcas* in the removal of heavy metals from contaminated soil of the Challawa industrial estate Kano, Nigeria. *Bayero J. Pure Appl. Sci.,* **10**, 579–583 (2017).

Agamuthu, P., O.P. Abioye and A.Abdul Aziz: Phytoremediation of soil contaminated with used lubricating oil using *Jatropha curcas. J. Hazard. Mate.,* **179**, 891–894 (2010).

Baker, A.J.M.: Accumulators and excluders-strategies in the response of plants to heavy metals. *J. Plant Nutr.,* **3**, 1–4 (1981).

Borman, G.D., G.P. von Maltitz, S. Tiwari and M.C. Scholes: Modelling the economic returns to labour for Jatropha cultivation in Southern Africa and India at different local fuel prices. *Biomass Bioenergy,*

59, 70–83 (2013).
Chang, F.C., C.H. Ko, M.J. Tsai, Y.N. Wang and C.Y. Chung: Phytoremediation of heavy metal contaminated soil by *Jatropha curcas*. *Ecotoxicol.,* **23**, 1969–1978 (2014).
Festa, R.A. and D.J. Thiele: Copper: An essential metal in biology. *Curr. Biol.,* **21**, 877–883 (2011).
Ghavri, S.V. and R.P. Singh: Growth, biomass production and remediation of copper contamination by Jatropha curcas plant in industrial wasteland soil. *J. Environ. Biol.*, **33**, 207–214 (2012).
Han, Q., J. Luo, Z. Li, H. Korpelainen and C. Li: Improved drought resistance by intergeneric grafting in Salicaceae plants under water deficits. *Environ. Exp. Bot.,* **155**, 217–225 (2018).
Ickert-Bond, S.M., J.M. Gerrath, U. Posluszny and J. Wen: Inflorescence development in the Vitis-Ampelocissus clade of Vitaceae: The unusual lamellate inflorescence of Pterisanthes. *Bot. J. Linn. Soc.,* **179**, 725–741 (2015).
Inafuku-Teramoto, S., C. Mazereku, T. Coetzee, C. Gwafila, L.A. Lekgari, D. Ketumile, Y. Fukuzawa, S. Yabuta, M. Masukujane, D.G.M. George, S.M. Chite, M. Ueno, Y. Kawamitsu and K. Akashi: Production approaches to establish effective cultivation methods for Jatropha (*Jatropha curcas* L.) under cold and semi-arid climate conditions. *Int. J. Agron. Plant Prod.,* **4**, 3804–3815 (2013).
Ishimoto, Y., S. Yabuta, S. Kgokong, M. Motsepe, J. Tominaga, S. Teramoto, T. Konaka, G. Mmopelwa, Y. Kawamitsu, K. Akashi and M. Ueno: Environmental evaluation with greenhouse gas emissions and absorption based on life cycle assessment for a Jatropha cultivation system in frost- and drought-prone regions of Botswana. *Biomass Bioenergy,* **110**, 33–40 (2018).
Jingura, R.M., D. Musademba and R. Matengaifa: An evaluation of utility of *Jatropha curcas* L. as a source of multiple energy carriers. *Int. J. Eng. Sci. Tech.,* **2**, 115–122 (2010).
Lyu, S., X. Wei, J. Chen, C. Wang, X. Wang and D. Pan: Titanium as a beneficial element for crop production. *Front. Plant Sci.,* **8**, 597 (2017).
Majid, N.M., M.M. Islam and Y. Riasmi: Heavy metal uptake and translocation by *Jatropha curcas* L. in sawdust sludge contaminated soils. *Aust. J. Crop Sci.,* **6**, 891–898 (2012).
Masia, N.D., N. Stevens and S. Archibald: Identifying phenological functional types in savanna trees. *Afr. J. Range Forage Sci.*, **35**, 81–88 (2018).
Mathiyazhagan, N. and D. Natarajan: Impact of mine waste dumps on growth and biomass of economically important crops. *J. Environ. Biol.,* **33**, 1069–1074 (2012).
Montes, J.M. and A.E. Melchinger: Demonstration and breeding of *Jatropha curcas* L. *Trends Plant Sci.,* **21**, 1045–1057 (2016).
Nagajyoti, P.C., K.D. Lee and T.V.M. Sreekanth: Heavy metals, occurrence and toxicity for plants: A review. *Environ. Chem. Lett.,* **8**, 199–216 (2010).
Ogura, T., Y. Date, M. Maskujane, T. Coetzee, K. Akashi and J. Kikuchi: Improvement of physical, chemical, and biological properties of aridsoil from Botswana by the incorporation of torrefied biomass. *Sci. Rep.*, **6**, 28011 (2016).
Pandey, V.C., K. Singh, J.S. Singh, A. Kumar, B. Singh and R.P. Singh: *Jatropha curcas*: A potential biofuel plant for sustainable environmental development. *Renew. Sustain. Energy Rev.,* **16**, 2870–2883 (2012).
Parawira, W.: Biodiesel production from *Jatropha curcas:* A review. *Sci. Res. Essays,* **5**, 1796–1808 (2010).
Porra, R.J., W.A. Thompson and P.E. Kriedemann : Determination of accurate extinction coefficients and simultaneous equations for assaying chlorophylls a and b extracted with four different solvents: Verification of the concentration of chlorophyll standards by atomic absorption spectroscopy. *Biochim. Biophys. Acta,* **975**, 384–394 (1989).
Quinn, L.D., K.C. Straker, J. Guo, S. Kim, S. Thapa, G. Kling, D.K. Lee and T.B. Voigt: Stress-tolerant feedstocks for sustainable bioenergy production on marginal land. *Bioener. Res.,* **8**, 1081–1100 (2015).
Shahid, M., B. Pourrut, C. Dumat, M. Nadeem, M. Aslam and E. Pinelli: Heavy-metal-induced reactive oxygen species: Phytotoxicity and physicochemical changes in plants. *Rev. Environ. Contam. Toxicol.,* **232**, 1–44 (2014).
Van Eijck, J., H. Romijn, A. Balkema and A. Faaij: Global experience with Jatropha cultivation for bioenergy: An assessment of socio-economic and environnemental aspect. *Renew. Sustain. Energy Rev.,* **32**, 869–889 (2014).
Van Wyk, B. and P. van Wyk: Field Guide to Trees of Southern Africa. 2nd Edn., Struik Nature, Cape Town, South Africa (2013).
Vurayai, R., B. Nkoane, B. Moseki and P. Chaturvedi: Assessment of heavy metal pollution/ contamination in soils east and west Bamangwato Concession Ltd. (BCL) Cu/Ni mine smelter in Selebi-Phikwe, Botswana. *J. Biol. Environ. Sci.,* **7**, 111–120 (2015).
Wani, S.P., G. Chander, K.L. Sahrawat, Ch.S. Rao, G. Raghvendra, P. Susanna and M. Pavani: Carbon sequestration and land rehabilitation through *Jatropha curcas* (L.) plantation in degraded lands. *Agri. Ecosyst. Environ.,* **161**, 112–120 (2012a).
Wani, T.A., S. Kitchlu and G. Ram: Genetic variability studies for morphological and qualitative attributes among *Jatropha curcas* L. accessions grown under subtropical conditions of North India. *South Afr. J. Bot.,* **79**, 102–105 (2012b).
Wicke, B., E. Smeets, H. Watson and A. Faaij: The current bioenergy production potential of semi-arid and arid regions in sub-Saharan Africa. *Biomass Bioenergy,* **35**, 2773–2786 (2011).
Yusuf, M., Q. Fariduddin, S. Hayat and A. Ahmad: Nickel: An overview of uptake, essentiality and toxicity in plants. *Bull. Environ. Contam. Toxicol.,* **86**, 1–17 (2011).
Zu, Y.Q., Y. Li, J.J. Chen,H.Y. Chen, L. Qin and C. Schvartz : Hyperaccumulation of Pb, Zn, and Cd in herbaceous grown on lead-zinc mining area in Yunnan, *China. Environ. Int.,* **31**, 755–762 (2005).