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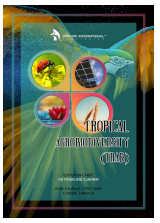

RESEARCH ARTICLE

RESPONSE OF POTATO (*SOLANUM TUBEROSUM* L.) TO THE APPLICATION RATES OF BIOCHAR AND NUMBER OF IRRIGATIONS

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ABSTRACT

A split-plot experiment was conducted to determine the response of potato to application rate of biochar (0, 2, 4 and 6 t/ha , main plots) and number of irrigations (once, twice and thrice a month, sub-plots) in 3 replications as a pot trial in a screen house at Khumaltar during winter season of 2018 and 2019. Biochar was produced from *Lantana camara* by semi-pyrolysed technique in a *Kon Tiki* drum. Plastic pots with 26 cm of diameter were used to meet the 25 cm plant spacing of potato recommended in Nepal. The early maturing (90 days) released variety 'Desiree' was used for the trial. Observations were recorded on plant and tuber attributes. The results revealed that the influence of biochar rates was positive over zero biochar on plant height, root fresh weight, root dry weight, stem fresh weight and tuber dry weight. The effect of biochar @ 2/ha had similar effects to the rates of 4 t/ha and 6 t/ha rates. Irrigation treatments were significantly different for plant height, number of tubers per plant, root fresh weight, stem and leaf fresh weight, tuber fresh weight, root dry weight and tuber dry weight. Among the irrigation schedules, irrigating twice and thrice a month had similar effects but they were different from one irrigation. Interactions of biochar @ 2 t/ha with one, two or three irrigations were superior to the interactions of biochar @ 0 t/ha with one and two irrigations for tuber dry weight and total dry weight.

KEYWORDS

dry weight, interactions, potato, biochar, irrigation

1. INTRODUCTION

Potato (*Solanum tuberosum L.*) is traditionally a vegetable crop and recently an emerging cash crop of Nepal. Its area, production and productivity were 195173 ha, 2881829 mt and 14.77 t/ha respectively in the fiscal year 2017/18 in the country (MOALD, 2019). Similarly, about 355913 mt of potato was imported from other countries while 536 mt was exported in the same year (DoC, 2019). The reason behind its high consumption is the use of potato as a staple food in the high mountains and as a main vegetable in the remaining part of the country. Comparing to other countries, the yields of potato were 20.4, 10.6, 18.8, 22.6, 15.8, 36.6 and 49.8 t/ha in Bangladesh, Bhutan, China, India, Nepal, The Netherlands and the USA, respectively in 2018 (FAOSTAT, 2019). Low productivity of potato relies on various factors such as irrigation, fertilizer, varieties, diseases, insect pests and management practices (NPDP, 2018).

Since lack of irrigation is faced by farmers of many areas of the country, there is no tool to reduce water requirement for potato crop. Some varieties have been released but no one is identified as drought resistant. In this context biochar was tested as a soil amendment to determine whether its high water holding capacity and other soil conditioning properties work or not to reduce water requirement of potato. Biochar is a 'black carbon manufactured through pyrolysis of biomass' (Lehmann et al., 2006). It can be produced from a wide range of biomass sources; for example, woods and barks, agricultural wastes such as olive husks, corncobs and tea waste green waste animal manures and other waste products (Ioannidou and Zabaniotou, 2007; Lima et al., 2008; Chan et al., 2007). Biochar is a mixture of char and ash with the major part (70 – 95%) carbon C (Brandstaka et al., 2010).

Some preliminary experiments on application of biochar in field crops of Nepal have proven its efficacy to enhance crop production. For example, some researchers found that production of legume and maize was increased by the application of *Eupatorium* biochar in acidic soil (<4.5 pH) (Pandit et al., 2015). Biochar application had positive impact on potato and other crops; however, its detailed study on potato crop is yet to be initiated (Vista et al., 2015). One of the studies carried out in potatoes showed no additional positive effect of plantain peel biochar and irrigation with fresh or waste water (Nzediegwu et al., 2019). However, biochar can increase plant growth and biomass under drought stress condition (Tayyab et al., 2018).

Similarly, efficacy of biochar on drought tolerance of crops is also a matter of study. Some studies have shown encouraging results. For example, a study on quinoa showed increased drought tolerance and water-use efficiency (Kamman et al., 2011). A study on tomato showed that biochar (30% v/v) significantly increased seedling resistance to wilting (Mulcahy et al, 2013). Another study done revealed that 9% mixture of yellow pine wood biochar pyrolyzed at 400^{0}C, doubled water holding capacity of loamy sand (Yu et al., 2013). In potato, biochar amendment indicated ameliorative effects in response to salinity stress and increased total tuber yield by 20% (Walter et al., 2015; Akhtar et al., 2015). Yet, literatures for the simultaneous efficacy of biochar and irrigation on crop growth and water requirement of potato are very limited. Thus this paper explains

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how potatoes respond to the application rates of biochar and the number of irrigations per month.

2. Materials and Methods

The experiment was conducted at Khumaltar in Lalitpur district (1350 masl) of Nepal. The experimental site was situated at a longitude of 27⁰ 38' 54.6'' N and at a latitude of 85⁰ 19' 30.9'' E. The weather was cool during January and February while it was warm during March onwards. The climate of this site was characterised by sub-tropical type. The experiment was conducted in a screen house which roof was made of transparent glass while the wall were covered with fine nets defined as insect-proof. The two-door system of house was designed to maintain the entry and exit to exclude insects pests outside. A split-plot experiment was conducted to determine appropriate combination of application rate of biochar (0, 2, 4 and 6 t/ha, main plots) and number of irrigations (once, twice and thrice a month, sub-plots) as given in Table 1.

The treatments were repeated in 3 replications as a pot trial during winter-spring season of 2018 and 2019. Biochar was produced from *Lantana camara* by semi-pyrolysed technique in a *Kon Tiki* drum provided by Soil Science Division, Khumaltar. Plastic pots with 26 cm of top diameter x 17 cm (bottom diameter) x 24 cm (height) were used to meet the 25 cm plant spacing of potato recommended in Nepal. The early maturing (90 days after planting) released variety 'Desiree' was used for the trial. This experiment was conducted in a media (1:1:2 FYM: sand: soil) amended with different doses of biochar. The amounts of biochar were calculated in hectare basis. The amount of soil in a 10-cm top soil in a hectare was a basis for determining amount of biochar in an area of a pot. Biochar was ground in a grinder to make fine powder before its application to the media. Before planting, a 15 cm deep pit was made with a hoe and calculated amount of biochar was deposited.

Water requirement for field capacity was determined for media by adding water to media until the water leached out of the pots. This amount was applied as a basal rate of initial irrigation. 75% of this amount was used in succeeding applications. Seed tubers with the size of 25-50 g were planted at 10 cm depth in the deposited biochar and covered with biochar and soil. Planting was done on second week of January and harvested in third week of April in both the years. The basal irrigation was applied on the following day of planting. No micronutrients and other supplementary chemicals were applied on foliage. Dry weights were recorded after drying samples in drying oven at 65⁰C for 72 hours. Observations were recorded on plant height, number of main stems per plant, number of tubers per plant, fresh weight of root, stems with foliage and tubers, dry weight of root, stems with foliage and tubers. Soil data were recorded on pH, organic matter, total nitrogen, extractable phosphorus and potassium at the laboratory of Soil Science Division of NARC. Data were analysed by Genstat version 18 (VSN International, 2015).

Table 1: Treatments of the experiment

SN	Main plot: Biochar rate (t/ha)	Sub-plot: Number of irrigations per month
1	0	1 (30 days interval)
2	0	2 (15 days interval)
3	0	3 (10 days interval)
4	2	1 (30 days interval)
5	2	2 (15 days interval)
6	2	3 (10 days interval)
7	4	1 (30 days interval)
8	4	2 (15 days interval)
9	4	3 (10 days interval)
10	6	1 (30 days interval)
11	6	2 (15 days interval)
12	6	3 (10 days interval)

3. Results and Discussion

3.1 Properties of biochar

Properties of biochar prepared from *Lantana Camara* and soil media were assessed for evaluation in the Chemical Laboratory of Nepal Academy of Science and Technology (NAST) and Soil Science Division of Nepal Agricultural Research Council (NARC). It was found that the biochar produced from *Lantana camara* contained very low available nitrogen (0.05%). However, the available nitrogen of the media or mixture of biochar, soil and sand was 0.95%. The FYM used in this experiment was one-year-old. In a report, old FYM contained about 0.6% available nitrogen but we did not analyse FYM separately (UH, 2011). Contents of Nitrogen, Phosphorus, potassium, total ash, electrical conductivity, pH and water holding capacity were estimated by the Chemical Laboratory of Nepal Academy of Science and Technology (NAST). According to the report, the following values given in the Table 2 were obtained:

Table 2: Analysis of biochar and soil media before experiment

SN	Parameters	Biochar	Medium (1:1:2 FYM: sand: soil)
1	Water holding capacity (%)	17.4	11.4
2	pH	9.6	5.2
3	Electrical conductivity (dS/m)	2.8	3.2
4	Total Ash (%)	11.0	-
5	Potassium (ppm)	10.4	52
6	Phosphorus (ppm)	3.41	172
7	Available nitrogen (%)	0.05	0.92

Biochar analyzed by NAST and medium analyzed by Soil Science Division, NARC

The values for water holding capacity, pH and electrical conductivity were greater in biochar than media while the amounts of nitrogen, phosphorus and potassium were greater in media than in biochar. The major reason behind less amount of nutrients in biochar would be the combustion of their part during pyrolysis. For example, pyrolysis in high temperature (600⁰C) had less water soluble NH_4^+ due to the loss and heterocyclization of N (Zheng et al., 2013).

3.2 Effect of biochar rates

The results revealed that significant differences (P = <0.05) were observed for plant height (Table 3), root fresh weight, stem and leaf fresh weight, root dry weight and tuber dry weight (Figure 1) due to the influence of application rates of biochar in both years. No significant differences were observed for number of main stems, number of tubers per plant, tuber fresh weight, total fresh weight, stem and leaf dry weight and total dry weight. Among the application rates, the rate of 6 t/ha was superior to 0, and 2 t/ha to increase plant height (Table 3). The increasing trend of plant height by increasing the rate of biochar indicated that the moisture absorbed by biochar could be a reserved source for continuous supply of moisture during the intervals of irrigations. Root fresh weight and stem and leaf fresh weight in 0 t/ha biochar were significantly lower than in 2, 4 and 6 t/ha biochar. For increasing root dry weight and tuber dry weight, the rate of 2 t/ha biochar was appropriate as it was found similar to other higher doses. The results also indicated that the influence of biochar on these parameters was greater in the first year as compared to the second year. It was mainly due to the less nutrient content in the media because we did not added sources of nutrients in the second year.

The influence of biochar rates on growth and development of potato are inadequately studied and study results are considerably varied. A group researchers found that there was no influence of biochar on growth of true potato seedlings and single node cuttings of true potato seedlings when tested in sand medium with supplementary nutrient solution (Upadhyay et al., 2014). In the present study, we tested in a soil - FYM - biochar medium. In the other results reported, wood biochar had negative effect on growth of potato (Liu et al., 2016). Yet, the influence may differ in application rates, for instance; a significant decrease in dry matter content of radish was obtained from 10 t/ha biochar (Chan et al., 2008). While in our experiment, biochar at a rate of 2 t/ha increased dry weights of potato as compared to no biochar. The reduced positive influence of biochar more than 2 t/ha on dry weight must be due to negative effect of possible increment in soil pH beyond neutrality. In other report, there was no significant effect of biochar rates (0, 7 and 15 t/ha) on turnip, wheat, rape and faba bean yields (Brandstaka et al., 2010). Biochar application increased vegetable yields by 4.7-25.5% as compared to farmers' practice (Vinh et al., 2014). A biochar significantly increased growth and yield of French bean as compared to no biochar (Saxena et al., 2013). A rice-husk biochar tested in lettuce-cabbage-lettuce cycle increased final biomass, root biomass, plant height and number of leaves in

comparison to no biochar treatments (Carter et al., 2013). However, the application of biochar was beneficial over no biochar to cabbage, lettuce, tomato and onion (Upadhyay, 2015).

Table 3: Effect of biochar rates on plant height of potato

Biochar rates (t/ha)	Plant height (cm)	
	1st year	2nd year
0	36.7 b	33.6 b
2	35.9 b	31.8 b
4	43.9 ab	42.3 ab
6	47.2 a	45.3 a
F-prob.	0.038	0.044
LSD (α 0.05)	8.91	7.88
CV%	21.2	18.4

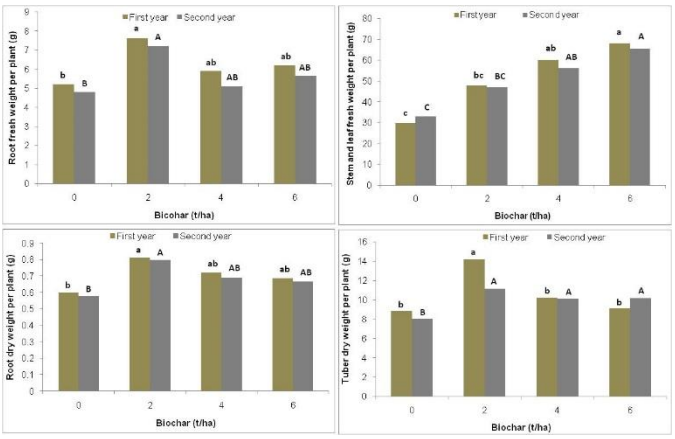

Figure 1: Root fresh weight, stem and leaf fresh weight, root dry weight and tuber dry weight influenced by biochar.

The different letters in the bars of same series indicate significant difference between treatments (N = 9) at α=0.05 level of significance. In the first year, LSDs for root fresh weight, stem and leaf fresh weight, root dry weight and tuber dry weight were 1.62, 18.42, 0.14 and 0.22 whereas CVs (%) were 14.4, 29.5, 22.2 and 16.8, respectively. In the second year, LSDs for root fresh weight, stem and leaf fresh weight, root dry weight and tuber dry weight were 2.31, 14.4, 0.17 and 1.13 whereas CVs (%) were 16.2, 22.3, 18.8 and 12.3, respectively.

3.3 Effect of number of irrigations

Significant differences (*P* = <0.05) were observed for plant height, number of tubers per plant (Table 4), root fresh weight, stem and leaf fresh weight, tuber fresh weight, root dry weight and tuber dry weight (Figure 2). Among the number of irrigations per month, two irrigations and three irrigations had similar but greater influence on plant height, root fresh weight, stem fresh weight, root dry weight, tuber dry weight and total dry weight as compared to one irrigation. The results implied that the biochar-added soil media could have similar influence of two and three irrigations per month in pots reflecting the possibility of reducing irrigations from three to two in a month. The reason behind this possibility must be the role of biochar for regulated supply of moisture and available nutrients to the plant in critical stages of the crop.

Responses of potato to water supply were reported in the past. According to a study, the growth parameters and the yield of potato significantly responded to the seasonal water supply with the increased tuber yield during the first season on the behalf of water supplied as compared to other (Abubakar et al., 2014). In our study, the water supply was done in intervals so that the differences were possible. A group researchers reported significant effects of irrigation water quantities on the number of stems of the potato plant, however we did not detect differences in number of stems in the present study (Islam et al., 1990). It was reported that water deficiency caused a reduction of yield by reducing growth of crop canopy and biomass whereas water deficiency also affected the plants in one irrigation per month in our study (Badr et al., 2012). The differences could also be observed if a comparison between pot and field trials could be made.

Table 4: Effect of number of irrigations per month on plant height of potato

Number of irrigations	Plant height (cm)		Number of tubers/plant	
	1st year	2nd year	1st year	2nd year
1	46.8 b	40.4 b	4 b	5 b
2	51.6 a	50.4 a	7 a	8 a
3	54.9 a	51.1 a	9 a	9 a
F-prob.	0.012	0.006	0.033	0.008
LSD (α0.05)	3.51	6.22	2.2	2.4
CV%	24.2	14.6	12.2	11.6

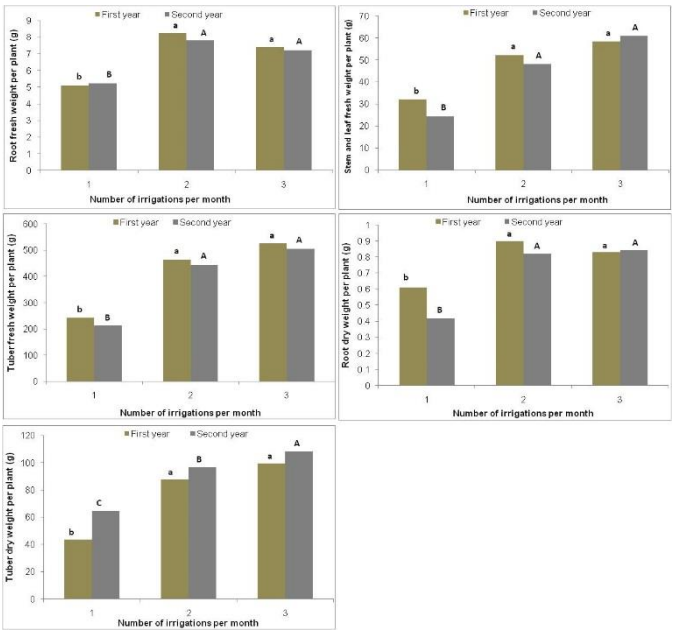

Figure 2: Root fresh weight, stem and leaf fresh weight, tuber fresh weight, root dry weight and tuber dry weight of potato influenced by number of irrigations.

The different letters in the bars of same series indicate significant difference between treatments (N = 12) at α = 0.05 level of significance. In the first year, LSDs for root fresh weight, stem and leaf fresh weight, tuber fresh weight, root dry weight and tuber dry weight were 1.09, 12.22, 137.7, 0.21 and 15.39 whereas CVs (%) were 23.5, 27.5, 13.6, 25.2 and 21.8, respectively. In the second year, LSDs for root fresh weight, stem and leaf fresh weight, root dry weight and tuber dry weight were 1.32, 17.41, 119.4, 0.21 and 10.44 whereas CVs (%) were 18.5, 16.6, 10.4 and 13.4 and 12.6, respectively.

3.4 Interaction effect

Interaction of biochar application rates and number irrigations per month had significant (P = <0.05) effect on tuber dry weight and total dry weight only (Table 5). Among the interactions, biochar rate of 2 t/ha along with single irrigation in a month was positively effective for tuber dry weight and total dry weight. Application of biochar rates with either one, two or three irrigations were superior to no biochar with one irrigation per month. Interactions of biochar @ 2 t/ha with one, two or three irrigations were superior to the interactions of biochar @ 0 t/ha with one and two irrigations. This result implied that the biochar could supply adsorbed nutrients and water continuously to support growth of tubers. Interaction of biochar and irrigations on growth and yield of crops is inadequately studied. However, irrigation and potassium interactions were studied in which differences were observed for the interactions of irrigation levels and potassium levels (Adhikari and Rana, 2018). In another study, conventional furrow irrigation was effective for growth and yield parameters of potato; indicating differences between irrigation methods (Verma et al, 2017). The addition of biochar under deficit irrigation helped to compensate for yield losses of vegetables and further enhanced water use efficiency (Singh et al., 2019). We also found that at least one irrigation could be cut off with the application of biochar. The similar effect of the interaction of 4 t/ha and 6 t/ha biochar with respective number of irrigations on tuber dry weight and total dry weight could be due to the increase in pH and change in other properties of media by biochar (Table 2) thereby restricted supply of some nutrients.

Table 5: Interaction effect of biochar rates and number of irrigations on performance of potato

Interactions		Tuber dry weight (g)		Total dry weight (g)	
Biochar rates (t/ha)	# of Irrigations per month	1st year	2nd year	1st year	2nd year
0	1	4.97 e	4.57 e	7.4 e	10.5 e
	2	6.1 de	5.7 de	9.9 de	13.0 de
	3	8.23 bcd	7.83 bcd	12.2 bcd	14.3 bcd
2	1	13.13 a	12.73 a	18.9 a	20.0 a
	2	11.3 ab	10.9 ab	16.4 ab	17.1 ab
	3	10.9 abc	10.5 abc	15.2 abc	16.9 abc
4	1	9.0 bcd	8.6 bcd	12.5 bcd	13.6 bcd
	2	7.1 bcd	6.7 bcd	13.0 bcd	15.9 bcd
	3	7.27 bcd	6.87 bcd	12.5 bcd	14.2 bcd
6	1	5.53 cde	5.13 cde	10.4 de	12.3 de
	2	8.1 bcd	7.7 bcd	12.3 bcd	14.1 bcd
	3	6.53 bcd	6.13 bcd	13.3 bcd	14.4 bcd
F-prob.		0.006	0.014	0.008	0.002
LSD α 0.05		2.194	2.210	3.888	3.169
CV%		13.5	10.8	18.8	10.5

4. Conclusion

The two-year experiment to determine appropriate combination of biochar application rate and number of irrigations on potato showed that the influence of biochar rates of 2. 4 and 6 t/ha was greater than that of 0 t/ha on plant height, root fresh weight, root dry weight, stem fresh weight and tuber dry weight. The effect of biochar @ 2/ha had similar effects to the rates of 4 t/ha and 6 t/ha rates. Irrigation treatments were significantly different for plant height, number of tubers per plant, root fresh weight, stem and leaf fresh weight, tuber fresh weight, root dry weight and tuber dry weight. Among the irrigation schedules, irrigating twice and thrice a month had similar effects but they were different from one irrigation. Interactions of biochar @ 2 t/ha with one, two or three irrigations were superior to the interactions of biochar @ 0 t/ha with one and two irrigations for tuber dry weight and total dry weight.

Author Contribution Statement

Kalika Prasad Upadhyay developed project activity and designed and managed the experiment. Janaki Datta Neupane assisted in recording data in entire experimental period. Both the authors read and approved the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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