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RESEARCH ARTICLE

Efficacy and environmental safety of flame weeding in the humid tropical region

K.D.B.V. Wijayasinghe*[1], M.H.S.M. Hettiarachchi[1], W.A.P. Weerakkody*, K.S.P. Amaratunga, P.I. Yapa[2] and K. Premathilake[3]

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ABSTRACT

Weed management in agriculture and landscaping is a great need, especially in the humid tropics where there is a vast species diversity and conducive environment for weed growth. High cost and residual effects of popular pre-emergent herbicides urge for low cost and eco-friendly alternatives. Even though manual weeding is eco-friendly, its small operational scale and low disturbance to the underground parts does not meet the efficacy of control. At this backdrop, thermal stress caused weed suppression by flame weeding was carried-out with the objective of detecting its efficacy as well as possible negative effects on the micro flora in the top soil. A five-burner flame weeder was used for the experiment conducted at the experimental farm of the University of Peradeniya, Sri Lanka (under humid tropical conditions) during the dry season in 2021, in a replicated trial. Moisture content of the top soil was maintained at near 40±8.5 % (w/w) of the field capacity. Rates of plant mortality and reemergence of three prominent weed species, and also the rate of suppression of the microbial population due to burning were determined before and after the application of flame. The theoretical and actual field capacity of flame weeding was 0.162 ha/hr and 0.119 ha/hr, respectively while weeding efficiency was 73.5 %. Effect of flame weeding on delaying re-immergence of broad leaves was faster than the sedges and grasses, limiting the rate of re-immergence of the weed population to initial population density by 24 days. Effect of flame weeding on micro-flora in soil is insignificant, both at the top level and at 5 cm depth. Eventhough CO2 emission rate (26.9 kg/ha) was higher than mechanical weeders, less frequent repeated weeding need makes it similar to them on seasonal or yearly basis. Based on its field capacity, weeding efficiency and environment friendly nature, flame weeding could be recommended to dry regions and seasons of the humid tropics.

Keywords*:* Eco-friendly, Recovery rate, Soil microbial biomass, Weed management, Weed types

INTRODUCTION

Agricultural lands occupy 20.7% of the total land area of 25600 km^2 in Sri Lanka while other countries in the humid tropical region of the world possess for even more percentage of extent of cultivation. This sector comprises of food crops (e.g. rice, other cereals, pulses, fruits and vegetables), plantation crops (tea, rubber and coconut) and spice crops (cinnamon, pepper, cloves and Nutmeg, *etc*.) (Central Bank Report 2016). Weeds, insect pests and pathogens are the three major biological factors affecting agriculture. Among these, weeds cause significant crop losses and yield reduction. The impact of weeds on productivity of food crops have been increasingly experienced worldwide. Marambe *et al.* (2009) estimates 50% crop losses due to weed competition in Sri Lanka. According to (Gharde *et al.* 2018) total actual economic loss due to weeds alone in 10 major field crops of India was estimated as USD 11 billion. Further it reduces the quality of crop harvest and threatens the native biodiversity. The annual global economic loss caused by weeds has been estimated at more than $100 billion U.S. dollars (Appleby *et al.* 2000). Several technologies are available for managing weeds in agricultural fields. One of the traditional methods for weed control is hand weeding. Smallholder farmers practice hand weeding by pulling or using simple tools such as hand-held hoe and inter-cultivators (Rao *et al.* 2017). However, labor shortage and tediousness in handling hard-to-pull grassy weeds (*e.g. Echinochloa crus-galli*), make hand weeding is less practicable. Mulching and intercropping are two agronomic methods used to suppress weed growth. Organic mulches such as leaf litter, rice straw, rice hull, saw

Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

[1] National Institute of Postharvest Management, Jayanthi Mawatha, Anuradhapura, Sri Lanka

[2] Faculty of Agricultural Science, Sabaragamuwa University of Sri Lanka

[3] Faculty of Agriculture, Uva-wellassa University of Sri Lanka

* Corresponding author email: pw2457@gmail.com

dust, *etc*. provide stronger physical barriers to all kinds of germinating weeds. Apart from that healthy ground cover (live mulch) maintained using less competitive weed species can also provide all-round protection for the crop. Meanwhile, another chapter in weed management opens up with weed suppression through allelopathy, which utilizes the inhibitory effects of phytochemicals secrete from the crop or companion species on the germination, early growth and reproduction of weed species (Saha *et al.* 2018). On top of all these options, the most popular option for weed control in agriculture is the use of synthetic herbicides. It was part of the large-scale agriculture introduced during the green revolution nearly 70 years ago in the world (Sharma and Singhvi, 2017). High efficacy and relatively low cost of herbicide application has made it popular among farmers all over the world, despite its negative impact on human health and the environment. Some nations and areas have outlawed the use of highly toxic herbicides. As an eco-friendly alternative to herbicide use, integrated weed management (IWM) in which farmers try to maintain the weed population below the economic threshold level.

Meanwhile with the recent boom in mechanization and automation, use of mechanical and power weeders or grass cutters have becoming increasingly popular among the farmers all over the world. Mechanical weeders were reported to reduce 74% of the need for labour and 72% of the cost of weed control (Islam *et al.* 2016). Shekhar et al. (2010) tested range of mechanical weeder options, namely field hoe, grubber, Khurpai and power weeder under hot and humid field conditions in India and found their actual field capacity (AFC) was 0.002 – 0.008 ha/hr while field efficiency (FE) was within 76.4–94.7%. Starting from tractor mounted conventional power weeders introduced in 1980s, and its versatile more popular version of man-operated brush cutter in 1990s, the global agriculture has moved to much more precise inter and intra row weeders such as sensor-based brush, finger and eco weeder, for large, raw planted fields and they have been further upgraded with artificial intelligence (AI) tools during last few years (Kumar *et al.* 2022, Vasileiou *et al.* 2023). However, fast re-growth of weed species from the undisturbed root system is a disadvantage for the use of power weeders. At this backdrop, "flame weeding" can be considered as another effective weed control option. Flame weeding is a type of thermal weed control method used from the late 1930s until the mid-1960s (Raffaelli *et al.* 2010, Ulloa *et al.* 2010). This relies on liquefied petroleum gas (LPG) burners to produce a carefully controlled and directed flame that briefly passes over the weed. Flaming is more effective on tender, herbaceous plants with high water content such as seedling or juvenile annual weeds, and particularly on broadleaf weeds. However, its efficacy in controlling grasses and sedges, and the possible damage the flame can do on useful flora and fauna in the eco-system and also its detrimental effects on soil flora and fauna are still debatable (Altheiri 1980, Abou *et al.* 2018). Therefore, this experiment was conducted to investigate the efficacy of flame weeding and investigate its side effects on soil and atmosphere under humid tropical conditions in Sri Lanka.

MATERIALS AND METHODS

Burner type and specifications

The flame weeder was fabricated in the Agriculture Engineering Department of the University of Peradeniya in Sri Lanka (**Figure 1a** and **1b**). It was a five-burner weeder, having a width of 90 cm and a 20 cm distance between adjoining burners. Weeder and the gas cylinder were mounted on to a steel frame and supported on to a push-cart type two-wheel frame. The unit was maneuvered by a waist height handle (**Figure 1a**). It was an "open-flame" type atmospheric burner that utilize LPG in gaseous form. The flame length was nearly 20±2.4 cm while the mean flame temperature was 1416±107.2° C. The nozzle size was 0.7 mm. Gas pressure was maintained within 3–5 x 10^{-5} Pa during the operation.

Experimental setup and design criteria

The field experiment was conducted in the experimental farm of the University of Peradeniya in Sri Lanka during March–April in 2021. The location belongs to mid-country wet zone of Sri Lanka, having an annual rainfall of 3000 mm and an average temperature of 28° C. The soil type of the region was red-yellow podolic (RYP). A flat land, which is subjected to grass cutting (moving) three months before the experiment was used for the flame weeder testing under dry weather conditions (having soil moisture content at 40±8,5 %. High temperature shock was given to weeds by applying a uniform flame by moving the weeder at the speed of 3-5 km/hr in a single run. Weeding was done in two-meter plots keeping five (05) replicates. Each plot contained all three types of weeds at a density of 18 -23 weeds ft^{-2} before flame weeding. Main three weed types, categoried according to their morphological features, namely grasses, sedges and broad leaves (Altieri,

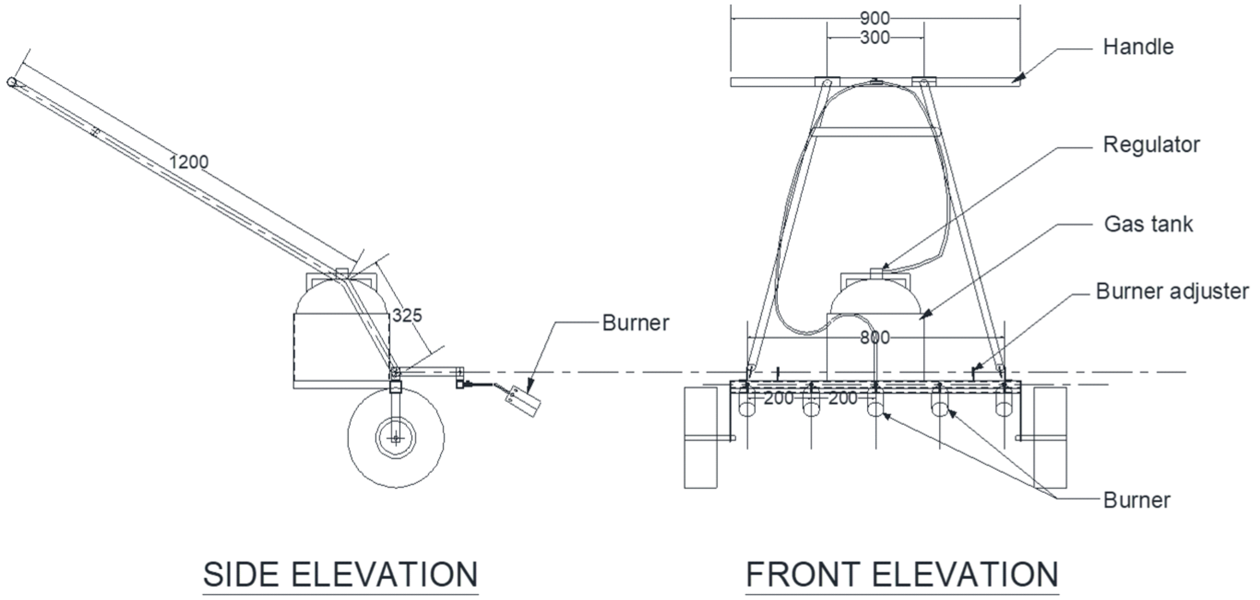

Figure 1a Main components of the five-burner flame weeder (dimensions are given in mm) [*Copy rights reserved*]

Figure 1b. Flame weeder – Front elevation (Left); Burner alignment and gas supply (top right); Burner mount and gas regulation (bottom right)

[Designed and manufactured by the Department of Agricultural Engineering, University of Peradeniya]

1988) present in each plot were considered as weed treatments (03) (independent variable) while the counts of three types of weeds (broad leaves, grasses and sedges) before and after weeding and microbial colony counts were considered as the assessment criteria (dependent variables).

Weeder performance testing

The weeder performance was tested on a flat grassy upland agricultural field during off-season (without having crops). Data collected for computing the following parameters to assess the weeder performance;

Table 1. Diversity of weed population at the research field

No.	Common name	Local (*Sinhala*) name	Botanical name	Family
01.	Coatbuttons[1]	*Kurunegala dasi*	*Tridax procumbens*	Asteraceae
02.	Coco-grass[3]	*Kaladuru*	*Cyperus rotundus*	Cyperaceae
04.	Citronella grass[2]	*Mana*	*Cymbopogon nardus*	Poaceae
05.	Blady grass[2]	*Illuk*	*Imperata cylindrica*	Poaceae
06.	Lilac tasselflower[1]	*Kadupahara*	*Emilia sonchifolia*	Asteracea
07.	Joy weed[1]	*Mukunuwenna*	*Alternanthera sp*	Amaranthaceae
08.	Copperleaf[1]	*Kuppameniya*	*Acalypha indica*	Euphorbiacea
09.	Little Ironweed[1]	*Monarakudumbiya*	*Vernonia cinerea*	Asteracea
10.	wild indigo[1]	*Kathurupila*	*Tephrosia purpurea*	Fabaceae

[1]Broad-leaves, [2]Grasses, [3]Sedges

Table 2. Weeding parameters of flame weeding

Parameter	Technical field capacity (ha/hr)	Actual field Capacity (ha/hr)	Field efficiency (%)	Weeding efficiency (%)
Value	0.162	0.119	73.5	93

Field capacity (FC): FC indicates the area (in hectares) covered by the weeder to completely exert its harmful action on weeds within a limited time (per hour), and was determined based on the following formula (Shekhar *et al.* 2010).

Theoretical field capacity $(TFC) = (WxS/\ 10)$ in ha/hr

where W – width in m; S – speed in km/hr

Actual field capacity (AFC) = Time taken in hrs to operate the weeder within a 1 ha field.

Field efficiency = (AFC/TFC) * 100

Weeding efficiency (WE): WE indicates the percentage number of weeds or weed biomass effectively controlled by the weeder in a given land mass after exerting its harmful action. It was determined using the following formulae (Shekhar *et al.* 2010).

WE = ((W1 – W2)/ W2) x 100 W1 – Weed count or biomass before weeding
W2 – Weed count or biomass after weeding

Determination of effect of flame weeding on re-emergence of weeds

After application of the gas flame on the weedy experimental plot, re-emergence or re-growth of each weed group were determined by counting them plot wise. Measurements were taken 7 days after the application of flame. Then data were collected on three-day intervals until 24th day after application of the flame. Weed suppression and re-growth was presented as a percentage of the initial weed count.

Determination of the effect of flame weeding on soil microbial population

Effect of flame weeding on soil microbial properties was examined immediately after the application of flame and also at 01 week after the application of flame. Here, soil samples were collected on the top of the soil layer and a 5 cm depth from the top layer. Microbial populations were counted as cfu/g with using four dilution series (10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}).

Estimation of GHG emissions by the flame weeder

Estimation of the emission of greenhouse gasses (GHG), namely CO_2 (carbon dioxide), CH_4 (methane) and NO_2 (nitrous oxide), by a standard gas nozzle fixed to the flame weeder within a unit time (per hr) was used to estimate the rate of GHG emitted by the flame weeder during its operation. Estimations were done by using the following parameter estimates and computational protocols.

Time of operation (hr/ha):

$$\text{Time of peration} = \frac{\text{length of the field x Number of turns}}{\text{Speed of movement}}$$

$$\text{Number of turns} = \frac{\text{Width of the field}}{\text{Flame or Cutting span}}$$

CO_2 emission per hectare (kg/ha):

$$\text{CO2 emmision} = \textit{CO2 emission rate x Time of operation x Fuel consumption}$$

Assumptions/ Constants:

CO_2 emission rate: Petrolium = 3.07 kg/L; LP gas = 2.98 kg/kg [2.3 L/kg]

(Ref. Watson and Gowdie, 2000)

Fuel consumption: Brush cutter = 500-750 Petrol L/ hr (Manufactures spcifications); Flame weeder = 1.46 LP gas kg/hr (Test results)

Statistical analysis of data

Five repeated weeding observations in different but equally dense field plots were taken for testing the detrimental effects of the flame weeder (replicates). Mean weed numbers and standard deviations of repeated tests were computed on each weed type.

The count data of weed and microbial coloney counts which were lower than 30 in number were subjected to non-parametric data analysis through Kruskal–Wallis test using statistical software, SPSS (IBM Coop 2020).

RESULTS AND DISCUSSION

Diversity of weed population at the research field

There were ten main weed species abundantly in the field which belong to the sub-categories, broad leaves, grasses and sedges **(Table 1).** Hence their propagules, rate of growth and impact resistance *etc.* must be entirely different.

Field capacity and weeding efficiency

Theoretical field capacity (TFC) was calculated based on the average moving speed of 1.8 km per hour. The width of the burner span moving at the average speed made TFC to be 0.162 ha per hour, slightly higher than the TFC of a brush cutter (0.154 ha/hr) but incomparable with power weeders (0.67 ha/hr) (Shekhar *et al.* 2010, Elkoud *et al.* 2022). Meanwhile the actual field capacity (AFC) tested during the weeding trials (**Table 2**) gave a similar value of 0.119 ha/hr to brush cutters (0.118 ha/hr) (Elkoud *et al.* 2022) but much higher than manual weeding gear (0.001 – 0.033) such as wheel hoe, grubber and Khurpi (Kumar et al., 2022). Hence the field efficiency (FE) was relatively lower (73.5 %) than brush cutters (76.6 %) (Elkoud *et al.* 2022).

As shown in **Table 2**. a relatively higher weeding efficiency (WE), calculated based on the number of weeds (93 %), was found compared to relatively low WE of power weeders (89.9 %), reported by Shaker et al. (2010). The reason could be the burning effect resulted on all flora on the ground by the flame.

Effect of flame weeding on re-emergence of weeds

According to **Figure 2**, dotted lines indicate the initial weed population of each type of weed, and solid lines indicate the regrowth of each weed types after flame weeding. Broad leaves type of weeds didn't reach to initial weed population even after 24 days of flame weeding. Sedges and grass type of weeds took 13 - 16 days after flame weeding and 16 - 19 days after flame weeding, respectively. From 13 - 24th days after flame weeding the regrowth rates between grasses and sedges are not significantly different and higher than broad leaves. The rate of regrowth of broad leaves is significantly lower than the other two weed types from the very beginning. Due to rapid regrowth, grasses and sedges should can be successfully controlled by repeated flame weeding at 10 - 16 days after the first weeding practice. But the control is very effective for broad leaves until 24 days after weeding or bit longer.

According to the studies conducted by Abou Chehade et al. (2018), application of pre-emergent weedicides (Glyphosate), showing a slight weed cover decrease of 15% (±7%) 27 days after the application or the weed cover did not increase and remained statistically in sedges type of weeds. But after flame weeding, regrowth increased up to 90–94% (±5%) 27 days after flame weeding. This fact could be assured by the current study with respect to regrowth of sedges after flame weeding. Another study has assured application of Nonanoic acid also for suppression of weeds but regrowth of sedges up to 98–100% (±5%) after 27 days of application (Sivalingam *et al.* 2022).

GHG emissions

As a part of the environmental impact of different weeding options, Greenhouse gas (GHG) emissions are considered. Compared to CO_2, the emission of other GHGs such as methane and N_2O are considered negligible for petroleum as well as LP gas burning. However, the rate of fuel consumption for a five-burner flame is relatively higher (1.4 L/hr) while it is 500 – 750 ml/hr for a brush cutter (with the capacity of 1.1 – 1.3 kW power). In the meantime, the rate of weeding and rate of CO_2 emissions are not much different between two optional weeding methods. Therefore, CO_2 emissions from flame weeding becomes significantly higher (26.9 kg/kg) than that of mechanical weeding such as brush cutters (14.9 kg/L). However, when consider a few

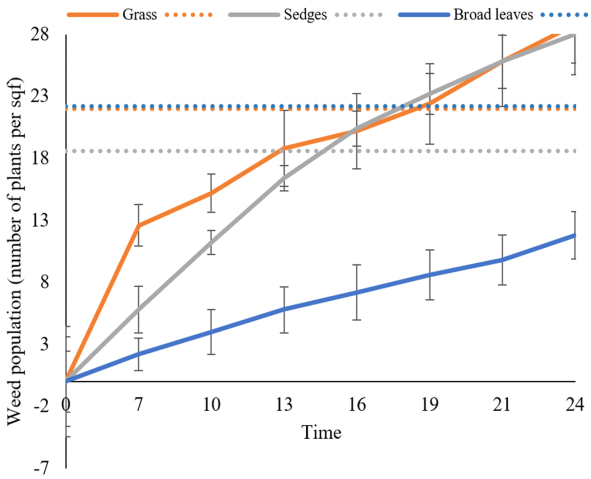

Figure 2. Rate of re-emergence of weeds after flame weeding
(Vertical bars indicate the SE of means at p=0.05)

months' period or a cultivation season, low recovery rate (**Figure 2**) under flame weeding requires less frequent repeated weeding compared to mechanical weeding. This is very much obvious when flame weeding of predominantly broad leaf weed infested fields. Therefore, GHG emissions from flame weeding could be either similar or lesser than mechanical weeding options for a relatively long period.

Effect of flame weeding on soil microbial population

According to **Figure 3**, a higher microbial population was observed in one week after flaming in top soil. The microbial population is decreased just after flaming in both top soil and soil in 5 cm depth. After one week of flaming, microbial population in both top soil and soil in 5 cm depth, increased than the initial population (Hatcher and Melander (2003) stated that flame weeding could be detrimental to some airborne as well as soil-surface-inhabiting organisms. Soil is a very good insulator and can absorb a significant amount of heat with little increase in temperature flame weeding the thermal treatment is brief and during the flame weeding only the uppermost few milli meters of the soil are heated. Therefore, a significant damage to the soil microflora or fauna is not expected during a normal flame weed control operation (Rahkonen *et al.* 1999).

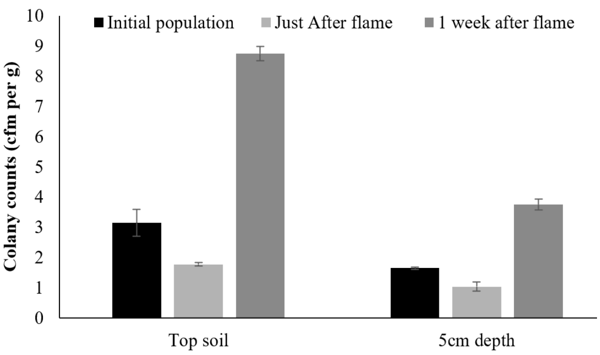

Figure 3. Suppression ad regrowth of microbial population at different soil depths
(Vertical bars indicate SE of the means at p=0.05)

Thermal weed control options are eco-friendly because they do not leave chemical residues in the crop, soil and water and can control herbicide-tolerant or resistant weeds, and provide rapid weed control. In the current study, flame weeding was found most suitable for controlling broad leaved weeds, because the population of broad leaves did not reach to initial population density even at 24 days after flaming. And also, the adverse effects of flame weeding on the microbial population was found to be insignificant. Therefore, the thermal (flame) weeding can be recommended for weed control under humid tropical conditions, particularly in the dry season.

Conclusion

The newly developed flame weeder is equally capable and efficient in weed control to common mechanical weeders in terms of weeding efficiency and actual field capacity. Eventhough its rate of GHGs emission is somewhat higher, less frequent repeated weeding need due to relatively high degree of weed suppression makes it insignificant in a long-run. Among different types of weeds, flame can control broad leaves much better than grasses and sedges. In addition to its lack of residual effect (agro-chemical) on the environment, the possible influence of flame weeding on soil microorganisms at shallow depths is considerable but their regain is much faster and greater. Hence five-burner flame weeder designed and manufactured by the Agricultural Engineering Department of the University of Peradeniya can be recommended as a high capacity, efficient and eco-friendly weeder for humid tropical countries.

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REFERENCES

Abou Chehade L, Fontanelli M, Martelloni L, Frasconi C, Raffaelli M and Peruzzi A. 2018. Effects of flame weeding on organic garlic production. *Hort Technology.* **28**(4): 502–508.

Altieri MA. 1988. *Ecological Approaches. Weed Management in Agroecosystems.* CRC Press, Boca Rattón, Florida, pp: 1–6.

Appleby AP, Muller F and Carpy S. 2000. Weed control, pp 687–707. In: *Agrochemicals* (Ed. Muller F.), Wiley Pub., New York.

Central Bank. 2016. *Sri Lanka Socio Economic D*ata, pp 1–2. Statistics Department, Central Bank of Sri Lanka, Colombo, Sri Lanka, Vol. XXXIX.

Gharde Y, Singh PK, Dubey RP and Gupta PK. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection* **107**: 12–18.

Gupta PK, and Tomar AK. (2019). Weed management in transplanted rice with special reference to *Commelina benghalensis* in the Kymore Plateau Satpura hills region of Madhya Pradesh. *Indian Journal of Weed Science* **51**(3): 236–239.

Hatcher PE and Melander B. 2003. Combining physical, cultural and biological methods: prospects for integrated non chemical weed management strategies. *Weed Research* **43**(5): 303–322.

Islam MS and Shirazul D. 2009. Farm mechanization for sustainable agriculture in Bangladesh: problems and prospects, pp 1–16. In: *Fifth APCAEM Technical Committee Meeting and the Expert Group Meeting on Application of Agricultural Machinery for Sustainable Agriculture*, United Nations Asian and Pacific Centre for Agricultural Engineering and Machinery, Manila, Philippines.

Kumar SP, Tewari VK, Mehta C R, Chethan CR, Chandel A, Pareek CM and Nare, B. 2022. Mechanical weed management technology to manage inter-and intra-row weeds in agroecosystems-A review. *Indian Journal of Weed Science* **54**(3): 220–232. http://dx.doi.org/10.5958/0974-8164.2022.00042.9

Marambe B, Wijesundera S and Silva P. 2009. Climate change and invasive alien species, pp 97–113. In: *First National Conference on Global Climate Change and its Impacts on Agriculture, Forestry and Water in the Tropics*. (Eds. Nissanka SP and Sangakkara UR.), University of Peradeniya, Peradeniya, Sri Lanka.

Raffaelli M, Fontanelli M, Frasconi C, Ginanni M and Peruzzi A. 2010. Physical weed control in protected leaf-beet in Central Italy. *Renewable Agricultural Food System* **25**(01): 8–15. http://dx.doi.org/10.1017/S1742170509990287.

Rahkonen J, Pietikäinen J and Jokela H. 1999. The effects of flame weeding on soil microbial biomass. *Biology Agriculture and Horticulture* **16**(4): 363–368.

Rao AN, Wani SP, Ahmed S, Haider Ali H and Marambe B. 2017. An overview of weeds and weed management in rice of South Asia, pp 247-281. In: Weed Management in Rice in the Asian-Pacific region (Eds. Rao AN and Matsumoto H.), *The Weed Science Society of Japan*, c/o Nakanishi Printing Co., Ltd., Kyoto.

Saha D, Marble SC and Pearson BJ. 2018. Allelopathic effects of common landscape and nursery mulch materials on weed control. *Frontiers in Plant Science* **9**: 733–745.

Shekhar S, Chandra S and Roy DK. 2010. Performance evaluation of different weeding tools in maize. *Indian Journal of Weed Science*, **42**(1&2): 95–97. https://www.extension.iastate.edu/agdm/crops/html/a3-24.html

Sharma N and Singhvi R. 2017. Effects of chemical fertilizers and pesticides on human health and environment: A review. *International Journal in Agriculture, Environment and Biotechnology* **10**(6): 675–680.

Sivalingam T, Swathi S, Balasubramanian A and Ramya K, 2022. Advances in weed management. pp. 159–193. In**:** *Compendium of Agriculture and Allied Sciences*. (Eds. Balamurugan *et al.*) JPS Publ. India.

Ulloa SM, Datta A and Knezevic SV. 2010. Growth stage impacts tolerance of winter wheat (*Triticum aestivum* L.) to broadcast flaming. *Crop Protection*, **29**(10): 1130–1135.

Vasileiou M, Kyriakos LS, Kleisiari C, Kleftodimos G, Vlontzos G, Belhouchette H and Pardalos PM. 2023. Transforming weed management in sustainable agriculture with artificial intelligence: A systematic literature review towards weed identification and deep learning. *Crop Protection*, p.106522.