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RESEARCH

Maize Cultivation and Adoption of Weed Management Technologies in Sri Lanka's North Central Province

B. Sanjeewa[1]*, L. Suriyagoda[2] and B. Marambe[2]

[1]*Department of Plant Sciences, Faculty of Agriculture, Rajarata University of Sri Lanka, Anuradhapura, Sri Lanka*
[2]*Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka*

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Sanjeewa, B.
https://orcid.org/0009-0008-8317-7780

*Corresponding author- tabsanjeewa@agri.rjt.ac.lk

ABSTRACT

Maize is the second most widely cultivated cereal in Sri Lanka. A field survey conducted from 2021 to 2022 assessed the present status and explored possibilities of increasing maize production in the North Central Province (NCP) of Sri Lanka. A pre-tested structured questionnaire was administered (n=56) together with farmer field observations (n=28), key informant interviews (KII; n=10), focus group discussions (FGD; n=5), and monitoring of selected farmer fields and practices at bi-weekly intervals (n=3). Data were analyzed using chi-square test (P=0.05) and correlation analysis using SAS statistical software. Two main maize-based cropping systems were identified in the NCP: rainfed upland maize monoculture (RUMM) and lowland paddy-based maize monoculture (LPMM). Crop-animal integration was reported by 21% of respondents bringing mutual benefits for both components. Approximately 61% of respondents were large-scale maize growers (2 to 10 ha) with mechanization and about 68% were full-time maize farmers who mostly used family labour. The net return from maize farming ranged from US$ 383 to 1,000 per ha. Younger maize farmers were found to be more educated than the elderly, however, there was a lower tendency for the younger generation to enter maize farming. Weeds are the main biological constraint for maize production with competitive weed species including *Megathyrsus maximus*, *Cyperus rotundus*, *Lantana camara*, *Ocimum sanctum* and *Euphorbia heterophylla.* Large-scale maize farmers used four-wheel tractors with land preparation implements for pre-plant weed control. The herbicides, Topramezone and Nicosulfuron were commonly used for post-plant weed control while small-scale farmers relied on manual methods and the same herbicides. Of the respondents, 23% used tank-mixed herbicides (cocktail mixtures); however, successful weed control was achieved without them. Moreover, 40% of respondents had access to herbicides not-registered in Sri Lanka. Results indicated that the import-ban on agrochemicals for seven months in 2021 led to the use of smuggled products.

INTRODUCTION

Maize (*Zea mays* L.; family *Poaceae*; tribe *Maydeae*) is recognized as the "queen of cereals" due to its high genetic production potential out of all cereals (Jhala *et al*., 2014), and considered the third important cereal globally, after wheat and rice. It is the most versatile crop, which is used as food, feed, fodder and as a source of bio-fuel (Perera and Weerasinghe, 2014), with a wider adaptability. Approximately, 1,148 million MT of maize was produced from an area of 194 million ha with an average productivity of 5.75 t/ha by over 170 countries. Nearly 34% of maize is produced by Asian countries (FAOStat, 2020).

Maize is the second most widely cultivated crop in Sri Lanka recording a gradual and significant increase in production from 2002 to 2019 due to the higher demand from the expanding animal feed industry and mechanized large-scale cultivation (Vidanapathirana *et al.,* 2021). Total national maize production in 2021 was approximately 472,444 mt from a cultivated area of 106,757 ha, yielding 4.4. Mt/ha. This production accounted for 79% of the total domestic requirement of 600,000 Mt/year (DCS 2021). Maize is predominantly a rainfed crop grown in both settled and shifting (chena) highlands during the *Maha* season (October-February). The North Central Province (NCP) comprising Anuradhapura and Polonnaruwa districts reported a cultivation of 47,463 ha (44% of the total extent) and a production of 256,628 Mt (54% of the total; DCS, 2021). Anuradhapura district, in particular, produced about 53% of the total maize in Sri Lanka (DCS, 2021) being the highest maize producing district of the country.

The major issues related to maize crop productivity in the NCP were identified as shortage of water, unavailability of fertilizers in sufficient quantities, pest and disease outbreaks, and weed competition where, weed competition was only second to the shortage of water (Kumari and Weerakoon, 2014). Approximately 37% of global maize production is lost due to weeds (Sharma and Rayamajhi, 2022). Due to the slow early growth rate and broader row-spacing of the maize crop, weed interference is a serious problem, especially in the early stages of crop growth. Apart from losses experienced in growth and yield, heavy weed infestation raises cultivation costs, lowers land value and decreases farmer's economic returns (Jhala *et al.,* 2014; Marambe *et al.,* 2015).

Large-scale farmers (2-10 ha of cultivated land) practice fully mechanized, rainfed cultivation during the *Maha* season. Some also practice shifting (Chena) cultivation without clear ownership of the land (PDOA-NCP, 2023). Mechanical land preparation using four-wheel tractor-mounted disk plough followed by tine tiller is considered the most cost effective and labor-saving method of weed control for large scale maize farmers (Malaviarachchi *et al.,* 2016). The small-scale farmers (<2 ha) usually cultivate maize in their fields for human consumption of immature cobs, irrespective of the season. They use partly-mechanized land preparation and manual weed control at post-plant stages with supplementary irrigation from tank water or Agro-wells (Vidanapathirana *et al.,* 2021).

Out of the total domestic requirement of maize, 83% is used by the poultry feed industry, 3% for other animal feeds, 7% for direct human consumption as boiled immature cobs, 6% for high nutrition foods such as "*thriposha*", and "*samaposha*" and 1% for alcohol production (Dr. Buddhika Abeysinghe, maize crop coordinator, Department of Agriculture - Personal communication). Maize production in the NCP dropped by 56% to 112,247 Mt during 2022, mainly due to the absence or shortage of synthetic fertilizers and pesticides for cultivation, resulting in a massive economic loss to maize farmers, the poultry industry, and other players in the value chain (DCS, 2022). However, the initial discussions we conducted with authorities of the Department of Agriculture (DOA) and the Provincial Department of Agriculture (PDOA) in the North Central Province, input suppliers and farmers clearly indicated the need for the rapid recovery of maize cultivation and production. The available data also revealed that weed control in maize within the NCP is approximately 14.5% of the total cost of production (DOA, 2019b). Hence, it is of national importance to resolve any issues in the maize production systems including weed management, to support the growth of the maize and animal feed industries. Therefore, the objectives of this study were to, (i) assess the present status of maize cultivation and maize farmers, (ii) identify maize-based cropping systems, (iii) identify dominant weed species, and (iv) evaluate the weed control methods and related practices currently used by the maize farmers in the NCP of Sri Lanka.

METHODOLOGY

This research included a questionnaire survey, farmer field observations, key informant interviews (KII), focus group discussions (FGDs) and monitoring of selected farmer fields and their practices, for data collection. The survey-based study was conducted with 56 selected farmers throughout the NCP of Sri Lanka using stratified random sampling method to represent all the Divisional Secretariat Divisions (DSDs), where maize crops are largely cultivated. All the 22 DSDs in the Anuradhapura district and 7 DSD's in the Polonnaruwa district were considered for selecting respondents for the questionnaire survey. The number of respondents selected from each DSD was approximately proportionate to the number of maize farmers in that DS division. In total, 50 farmers were selected from the Anuradhapura district which had a cultivated extent of 46,778 ha in 2021 and six from the Polonnaruwa district which had a cultivated extent of 686 ha in 2021. A list of maize farmers in the Agrarian Service Centers (ASCs) was used to select the maize farmers within each DSD. The location of each respondent farmer was identified using GPS co-ordinates. We decided to pool the district-wise data into an NCP database due to the similarity of data on maize farmers in Anuradhapura and Polonnaruwa districts and the lower number of maize farmers reported from Polonnaruwa. The survey was conducted during the period 2021 to 2022. A structured survey questionnaire was developed and pre-tested at the study site before finalization. The survey questionnaire included sections on demographic details of maize farmers, maize-based cropping systems, cultivated extent, adoption of animal husbandry by maize farmers, use of farm machinery, fertilizer and water management, constraints for maize cultivation including dominant weeds, weed management practices including the use of herbicides, cost of total cultivation and weed management, and marketing of produce.

Data collection

The finalized structured questionnaire was the first data collection tool utilized in this research. The survey questionnaire (n=56) was completed by the first author of this paper, who asked questions and engaged in discussions with the respondent farmer while observing their cultivation process to enhance question clarity and answer accuracy. Further, questions that the respondent was not aware of or could not answer were omitted by the researcher. Farmer field observations (n=28) were conducted in conjunction with the survey to provide insight into the actual field conditions. Among them, two randomly selected maize farmers in Saliyapura and Nochchiyagama in the Anuradhapura District and one farmer at Kaduruwela in the Polonnaruwa District were visited once in two weeks to study their cultivation/management practices in detail at the farmer level. In all visits, attention was paid to identify the dominant weeds, and weed identification was done with the help of a systematic botanist after collecting weed samples.

Survey findings were also strengthened by Key Informant Interviews (KII; n=10), focus group discussions (n=5), and regular monitoring of selected farmer fields and practices (n=3). Interviews and discussions were conducted with the leader farmers, Agriculture Instructors (AI), research officers attached to the Field Crops Research and Development Institute (FCRDI) at Mahailluppallama, and members of the CropLife-Sri Lanka (the association of pesticides-importing companies).

Data analysis

All data collected using survey questionnaires were entered into a spread sheet environment. Data gathered from questionnaires related to selected variables were statistically analyzed using the chi-square test and Spearman correlation using SAS statistical software (SAS, 2000). Data gathered from observations, discussions, interviews and monitoring farmer fields and practices were recorded, and analyzed in a descriptive manner while also comparing them with data obtained using other tools.

RESULTS AND DISCUSSION

Maize-based cropping systems in the NCP

As observed in the present study, 76% of arable lands in the NCP were large-scale rainfed highlands that are not suitable for paddy cultivation (PDOA-NCP, 2023). They are usually used for field crops such as maize, gingerly, black gram and green gram in the NCP, especially during the *Maha* season (PDOA-NCP, 2023). Maize cultivation in such locations could be identified as "Rainfed upland maize monoculture cropping system" (RUMM). This cropping system contributes to more than 75% of the maize production in the NCP. Champika and Abeywickrama (2014) reported that 89% of the maize cultivated extent is in the *Maha* season in upland rainfed fields. The RUMM is also practiced in areas closer to forests in the form of chena cultivation making the protection from wild animals a difficult task, and thus increasing the risk of crop yield losses due to macro pest attacks.

Maize cultivated in paddy lands that did not receive sufficient quantity of irrigation water for the paddy crop, especially during the *Yala* season (Figure 3A) was identified as "Lowland paddy-based maize monoculture cropping system" (LPMM). Further, there were minor cropping systems where maize was found as a component crop, namely, "Agrowell-based continuous maize monoculture cropping system" (ACMM) (Figure 3A), "Cattle farming-based maize monoculture cropping system" (CFMM) (Figure 1) and "Homegarden-associated maize polyculture cropping system" (HGMP).

The results indicated that animal husbandry integrated with maize farming has supported providing animal feed, and in return, manure for the crop. Silva *et al*. (2012) reported that animal integration in the maize-soybean-pasture system in Brazil has increased dry matter and grain yield of the crops. Crop-animal interactions in the Philippines has mutually benefitted each other including weed control by grazing animals, animal manure to enhance soil fertility and animal feed from crops (Sombilla and Hardy, 2005). Similarly, in the Sri Lankan context, maize-animal integration would mutually benefit each component provided that the crop is not damaged by the animals.

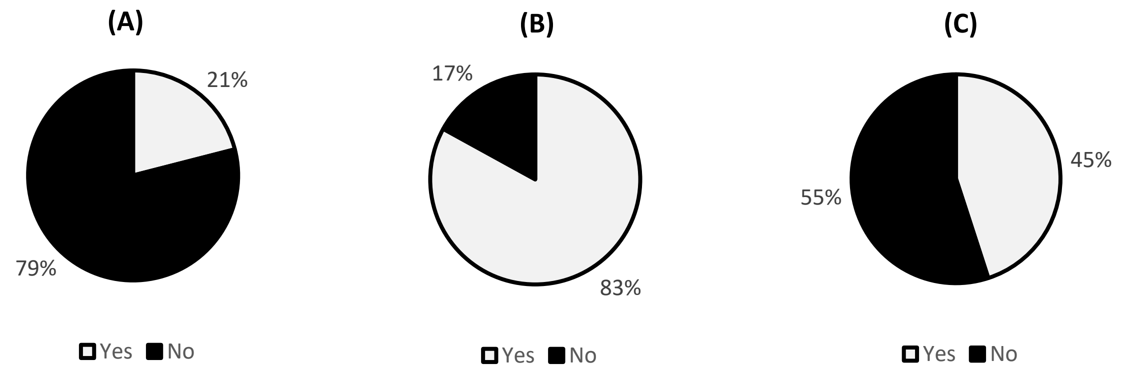

Figure 1. The level of integration of animal husbandry by maize farmers; (A) Availability of animal husbandry, (B) Feed maize plants to animals, (C) Application of animal waste to maize fields.

Demographics of Maize Farmers in the NCP

About 60% of the surveyed farmers were middle-aged between 41 and 60 years (Figure 2A), recording an average age of 49.5 years for the sample. Engagement of the younger generation in maize farming was low: only 8% of the surveyed farmers were below 30 years old and 17% were between 31 and 40 years old (Figure 2A), while 50% of the respondents started maize farming at an age below 30 years of age (Figure 2C). Champika and Abeywickrama (2014) reported that the average age of maize farmers in the Anuradhapura district was 42 years. Hence, as revealed in the present study, increase in the average age of maize farmers during the last 10-years also provides evidence for less tendency of the younger generation to move into maize farming. This phenomenon also leads to a reduction of the number of farmers engaged in maize farming, thereby increasing land holding size per farmer resulting in informal land consolidation (FGD).

Age and farming experience were positively correlated ($P<0.05$; Table 1). Farming experience was negatively correlated with cultivation costs ($P<0.05$) as experienced farmers could reduce costs by using cost-saving technologies. However, farming experience was negatively correlated with maize yield indicating that experienced farmers were achieving lower yields (Table 1) compared to younger farmers. This is probably due to younger farmers being early adopters of new technologies due to their exposure to the knowledge resulting in higher maize productivity. Moreover, the level of education showed a weak negative correlation with age ($P=0.0819$; $r=-0.2435$; Table 1), suggesting that younger farmers were more educated than elderly farmers. Similar findings were reported by Lindsjö *et al.* (2021) who concluded that sustainable agriculture intensification would remain low until youth participation increases.

The results of the KIIs and FGDs indicated that maize farmers also cultivate paddy, other field crops, grain legumes, vegetables and rear animals adding to their farming experience. However, in contrast to many previous findings, the farming experience and the level of education in the respondents did not correlate significantly with weed control ($P>0.05$), while the level of education had no significant correlation with the cost per hectare per season or maize yield ($P>0.05$; Table 1). Khan *et al*. (2012) reported that professional qualifications, family background and regular trainings are significantly related to farmer capability in weed management. Eric *et al*. (2014) reported that non-formal education provides hands-on training to farmers while with formal education, farmers are adapting to changing environments and share the experience gained, thus, supporting progression in farming.

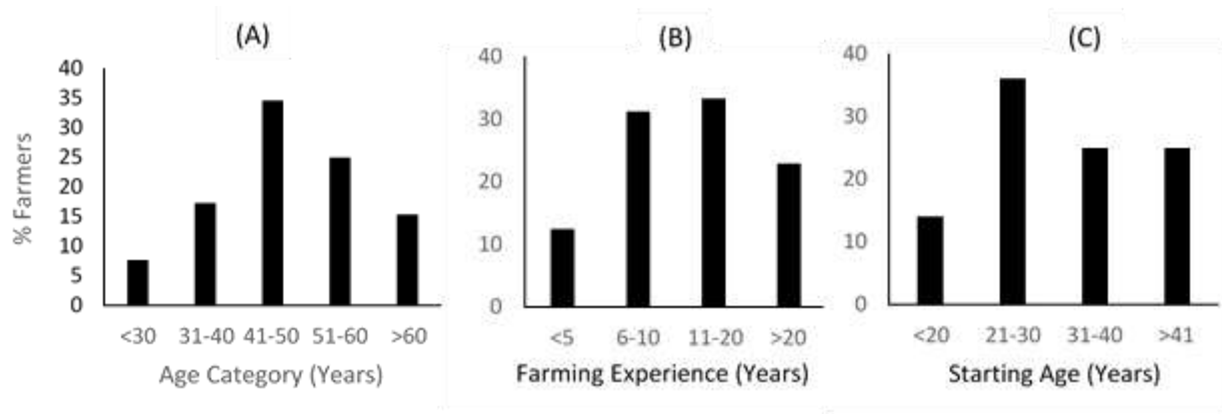

Figure 2. Distribution of (A) Age of farmers, (B) Farming experience, and (C) Starting age of maize farming, among the farmers tested in NCP

Table 1. Spearman rank correlation between Farming experience and Level of education *vs* Age, Cultivation cost per hectare per season, Weed control and Maize yield per hectare.

Farming Experience *vs*	**Age**	**Cultivation Cost (ha^{-1} $Season^{-1}$)**
r	0.3710	−0.3015
Prob> |r|	0.0080	0.0353
# Observation	50	49
Farming Experience *vs*	**Weed Control**	**Maize Yield (ha^{-1})**
r	0.0749	-0.3011
Probability > |r|	0.6052	0.0471
Number of Observations	50	44
Level of Education *vs*	**Age**	**Cultivation Cost (ha^{-1} $Season^{-1}$)**
r	-0.2435	0.2213
Probability > |r|	0.0819	0.1265
Number of Observations	52	49
Level of Education *vs*	**Weed Control**	**Maize Yield (ha^{-1})**
r	0.1948	0.2293
Probability > |r|	0.1621	0.1297
Number of Observations	53	45

Cultivated Extent of Maize in the NCP

The cultivated area of a single maize farmer in the study sample ranged between 0.4 ha and 10 ha (Figure 3B). The survey revealed that 61% of maize farmers were in the category of large-scale (2 to 10 ha) while the rest were small-scale farmers (Figure 3C). During the *Maha* season, 76% of the surveyed farmers cultivated maize as a rainfed crop (Figure 3A), on areas larger than 2 ha using mechanized methods (Table 2). Cultivation in the *Yala* season was irrigated (flood irrigation from both major and minor irrigation schemes) with a smaller sown area (DCS, 2021).

Mechanization of Maize Cultivation in the NCP

Mechanization of crop cultivation in Sri Lanka is an evolutionary process and has spread to maize cultivation from the year 2000. The country has reached a significant level of mechanization during the past 10 years compared to other countries in Asia and Africa with the mechanization of land preparation, seeding and threshing (Abeyratne and Takeshima, 2020).

The present study showed that maize cultivation in the NCP was highly mechanized (Table 2). Many farmers in the study sample, regardless of the size of their cultivations, used two or four-wheeled tractors (Table 2) mounted with a disk plough for ploughing, a tine tiller for harrowing, and a level bar for levelling. This same equipment was also used for pre-plant weed control. Some farmers opted to broadcast seeds with the onset of rains and then used the tine tiller to cover the seeds with soil as a labor-saving technique. Field observations, KIIs and FGDs confirmed that farmers in the NCP used lever-operated knapsack sprayers, battery-operated knapsack sprayers, and power sprayers for the application of herbicides and pesticides. Grass cutters were employed for pre-plant weeding especially under heavy weed infestations and for clearing bunds and canals. In addition, some farmers had developed their own machineries for the seeding, fertilizer application and earthing-up.

Moreover, small-scale farmers (<2 ha) used manual methods such as the hoe (mammoty; *Udella*) and hand weeding for weed control while large-scale farmers (2-10 ha) used chemical herbicides such as Topramezone (Clio®) (Pigment inhibitor; Rao, 2005) and Nicosulfuron (Topaz®) (ALS Inhibitor; Rao, 2005) as post-plant weed control methods. Harvesting was mostly manual and threshing was mechanical by using a combined thresher (Table 2). Maize farmers in the NCP did not use combine harvesters due to the mismatch of the machines introduced to the local market for the said purpose.

The FGDs indicated that manual post-plant weeding in one hectare in the NCP of Sri Lanka using the hoe consumes 80 man-hours with an approximate cost of LKR 35,000 (US$ 116.67). Mechanical pre-plant weeding of one hectare in the NCP using a grass cutter required approximately 40 man-hours (FGD). Ishaya *et al.* (2007) reported that maize cultivation in Nigeria utilized 309 man-hours per hectare. The man-hours for post-plant weeding is probably low in Sri Lanka due to land tilling as against zero or minimum tillage in countries like Nigeria. However, maize cultivation in many other countries are mechanized (Giuliano *et al*., 2021; Susha *et al*., 2018) where both mechanization and chemical weeding have significantly reduced the labour requirement, labour cost as well as overall cost of production of maize while increasing the profit of farmers.

The outcome of the KIIs highlighted that large-scale maize farming is highly profitable ensuring the retention of farmers with maize cultivation. The net return in RUMM is between 250,000 – 300,000 LKR (approx. US$ 833 – 1,000) per ha, and in LPMM is between 115,000 – 125,000 LKR (approx. US$ 383 – 416) per ha. The net returns reported in this study were higher than those reported for maize farming in the Mahaweli system H in the NCP, which belongs to LPMM; i.e., 101,902 LKR (approx. US$ 340) per ha (DOA, 2019b).

Survey results revealed that the majority of respondent maize farmers (68%) were engaged in farming fulltime, while 26% had government jobs, and the rest (6%) had other income sources such as hiring machinery and supplying labour for construction work (Figure 4A). None of the respondents were employed in the private sector or in their own non-agricultural businesses. The outcome of the FGDs highlighted the significant amount of time spent on maize farming unlike in the case of paddy. About 68% of the farmers used family labour for maize farming while the rest used hired labour when needed (Figure 4B). Champika and Abeywickrama (2014) reported that maize farmers in the Anuradhapura district had non-agricultural income and used family labour for their cultivation-related practices. The present study also revealed that the use of family labour for maize farming is more dominant than using hired labour (Figure 4B).

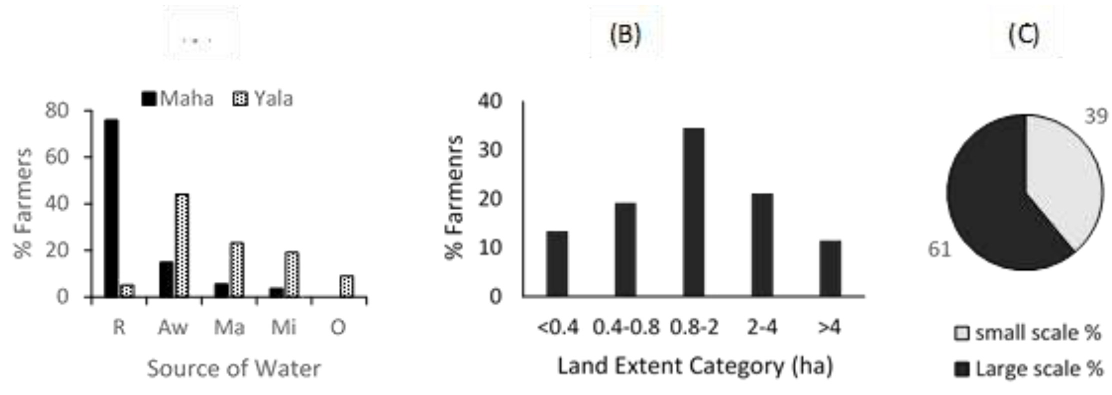

Figure 3. Sources of irrigation water (A) (R - Rainfed, Aw - Agro-well, Ma - Major Irrigation, Mi - Minor Irrigation, O - Other), Cultivated land extent by a single maize farmer (B), and Scale of maize cultivation (C)

Table 2. Use of Different Farm Machinery for Maize Cultivation in the North Central Province of Sri Lanka

Machinery Usage	Two-Wheel Tractor	Four-Wheel Tractor	Sprayer	Grass Cutter	Thresher	Combine Harvester*	Other Machinery**
	%						
Not Used	38.5	25.0	23.1	34.6	42.3	93.6	27.7
Hired	34.6	51.9	34.6	30.8	51.9	6.4	33.5
Use own machines	26.9	23.1	42.3	34.6	5.8	0.0	38.8

* Combine harvester – Self-propelled corn combine harvester
** Other machinery – Seeders, hoeing machinery, Farmer-made machines

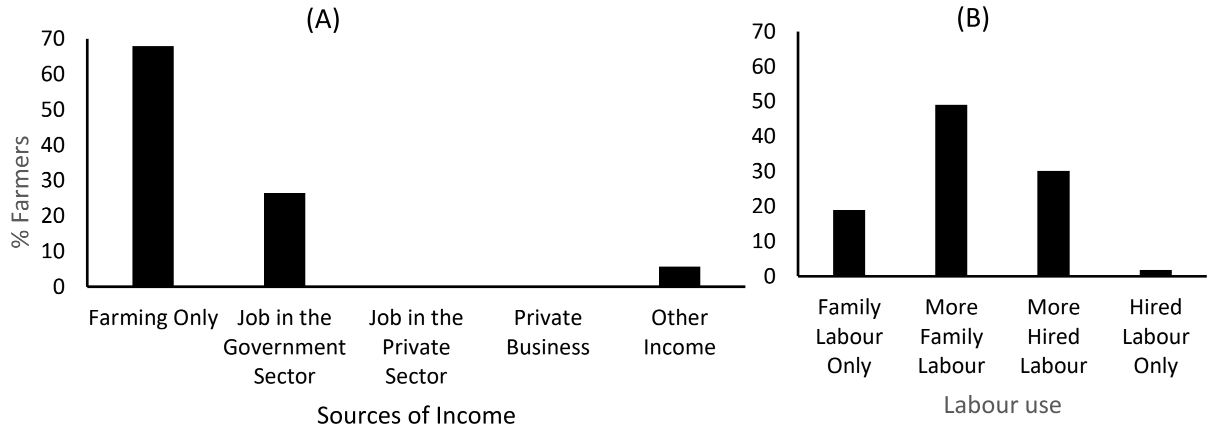

Figure 4. Distribution of (A) Sources of income, and (B) Labour-use for cultivation by maize farmers (Note: 'more family labour' indicates that more than 50% of the required labour is provided from own family)

Constraints for maize cultivation

The major constraints for maize cultivation were insects and macro pests, disease outbreaks, weed incidence, shortage of water and unavailability of fertilizers (Figure 5). Of these, 32% of the farmers considered weeds as a major constraint for maize cultivation which ranked first in the NCP (Figure 5). The incidence of Fall Army Worm (*Spodoptera frugiperda*) since 2019 and stalk borer (*Busseola fusca*) were the only prominent insect pests of maize (Malaviarachchi *et al.,* 2016). Lack of protection from wild animals (elephants, peacocks and monkeys) was also a significant constraint in certain locations. Water was a limiting factor for uplands where rainfed cultivation is usually practiced. Fertilizer had become a constraint after the agrochemical import restriction was imposed in May 2021, which was removed in November 2021. The economic downturn of the country made agrochemical importation a difficult exercise for a certain period (Rathnayake *et al.,* 2024) and those imported chemicals were costly due to the appreciation of foreign currencies in relation to the Sri Lankan Rupee (LKR). Proper weed control measures should be adopted at the beginning of any cultivation as weeds exert a significant pressure on the crop throughout the growth cycle. The KIIs of the study revealed that uncontrolled weeds cause yield losses since weeds are not visible to many maize farmers at the initial stages, and thus, rendering their control more difficult as reported by Champika and Abeywickrama (2014).

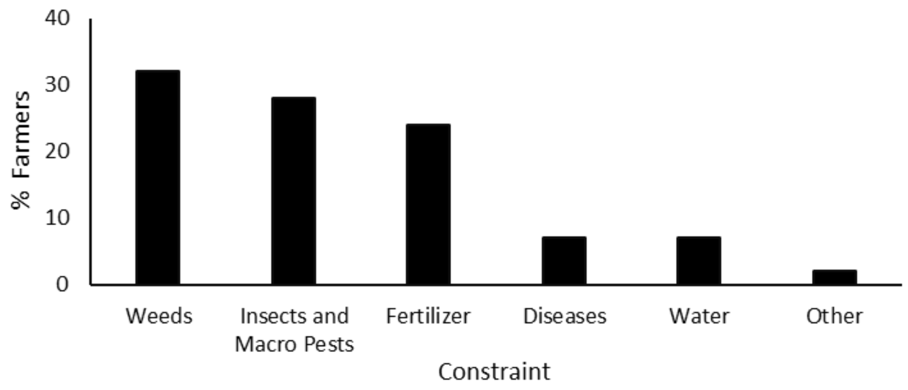

Figure 5. Major constraints for maize cultivation prevailed in the NCP of Sri Lanka

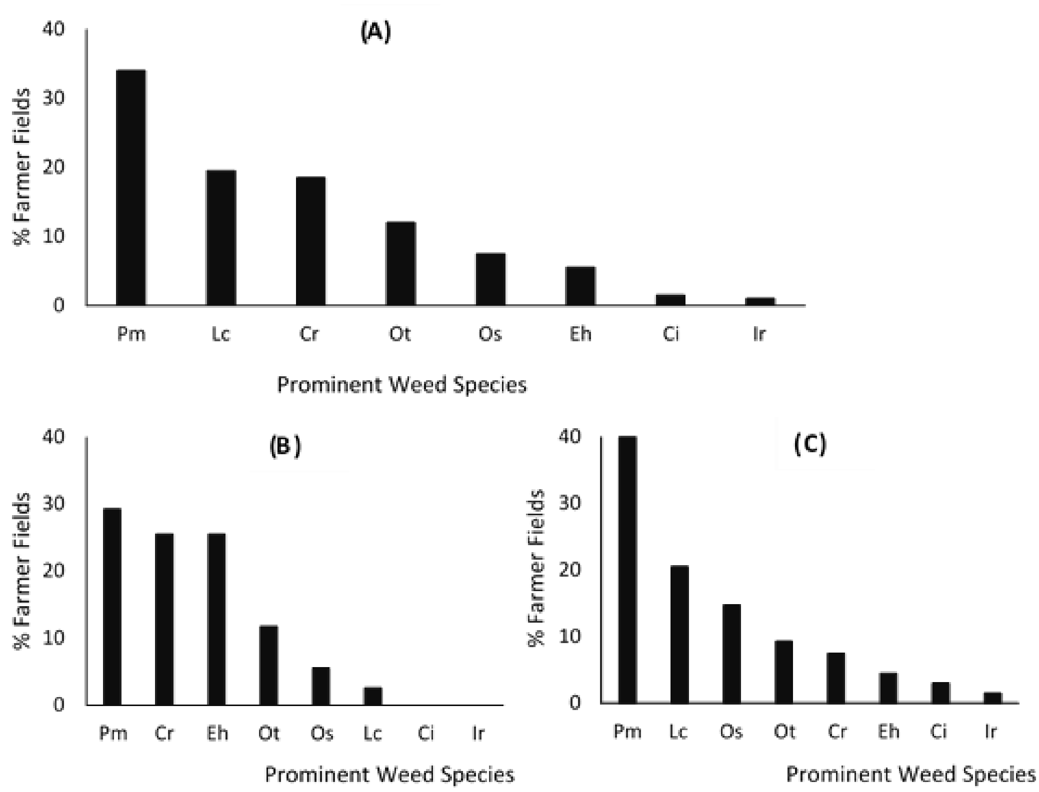

Figure 6. Relative abundance of troublesome weed species in maize cultivations (A), Prominence of troublesome weed species in (B) rainfed upland maize monoculture – RUMM, and (C) Lowland paddy-based maize monoculture cropping system - LPMM; Pm = *Megathyrsus maximus*, Lc = *Lantana camara*, Os = *Ocimum sanctum*, Ot = Others, Cr = *Cyperus rotundus*, Eh = *Euphorbia heterophylla*, Ci = *Cyperus iria* and Ir = *Ischaemum rugosum*

Troublesome weed species in maize cultivations in the NCP

The results of the present survey revealed that *Megathyrsus maximus* (Guinea grass), *Cyperus rotundus* (Purple Nutsedge), *Lantana camara* (Common lantana), *Ocimun sanctum* (Holy Basil) and *Euphorbia heterophylla* (Mexican fire plant), *Cyperus iria* (Rice flat sedge) and *Ischaemum rugosum* (Saramolla grass) were the most troublesome weed species found in maize cultivations in different cropping systems in the NCP of Sri Lanka (Figure 6). Different weed species become dominant in a location due to ecological reasons (Alptekin *et al.,* 2022; Susha *et al.,* 2018). Weeds may occur in locations with inconsistencies such as changes in soil texture, organic matter content and soil humidity within a field (Sharma and Rayamajhi, 2022). Accordingly, the outcome of this study highlighted the changing dominance of weed species with the cropping system.

Of the troublesome weed species, *M. maximus* (grass), *L. camara* (broadleaf) and *O. sanctum* (broadleaf) are perennials that were dominant in the RUMM, while the perennials such as *C. rotundus* (sedge) and *M. maximus* (grass) and the annual *E. heterophylla* (broadleaf) were dominant in LPMM (Figure 7).

Weed control methods used by maize farmers in NCP

Herbicides were the most widely used tool (85%) especially in post-plant weed management of maize (Figure 7) in all maize-based cropping systems, except HGMP, in the NCP. All the large-scale farmers and a considerable proportion of small-scale farmers used herbicides. This provided the basis for giving priority in this paper to the use of herbicides to control weeds by the farmers. The KIIs and FGDs also revealed that all large-scale farmers and a considerable proportion of small-scale farmers practiced primary land preparation using four-wheel tractors (Table 2), which has also helped in pre-plant weed management in maize farming in the NCP, as explained by Abdullah *et al.* (2024). However, the majority of farmers did not consider land preparation as a weed control method, as the primary aim was to provide a good soil tilth for crop growth. Only 2% of the respondents identified agronomic methods including land preparation as their best weed control method.

Maize farmers used integrated weed management, where they applied mechanical, manual, cultural and chemical methods of weed management during the crop growth cycle. However, the majority of farmers considered herbicides as their most successful post-plant weed control method, followed by mechanical control (Figure 7). Sharma and Rayamajhi (2022) also reported that chemical methods are the most widely used in weed management in crop production systems, though physical, cultural and biological methods have their own advantages. Integrated weed management is considered as the most successful method in the long-term to minimize weed competition and resistance development to herbicides (Sharma and Rayamajhi, 2022; Hetta *et al*., 2022).

Use of herbicides for weed control

The majority of farmers in all the maize-based cropping systems did not use pre-plant herbicides (Figure 8), where pre-plant weed control, as explained before, has been involuntarily achieved through land preparation. The absence of pre-plant herbicides (e.g. paraquat and glyphosate) in the Sri Lankan market during the study period would also have affected this. Import and use of Paraquat was banned in 2014 (DOA, 2020), while glyphosate was allowed to be used only for tea and rubber cultivation (Marambe and Herath, 2022; Dorlach and Gunasekara, 2023), a decision that was effective during the survey period. However, few farmers still had access and used the banned chemicals or used other options (Figure 8) as they perceived that the use of pre-plant herbicides was convenient and effective. One of the key informants and few other respondents had purchased paraquat from the Galenbindunuwewa Divisional Secretariat Division (DSD) area through their personal contacts who were not registered pesticide retailers. The outcome of the KIIs highlighted the availability of paraquat, carbofuran and few other banned herbicides in the open market, mostly smuggled from India. A glyphosate product not registered in Sri Lanka, but of Indian origin (according to its label), was freely available in the NCP (Figure 8). It was available even with the registered pesticide retailers, which is alarming owing to their human health and environment-related issues pertaining to pesticide products that are not registered and evaluated in Sri Lanka. The KIIs also revealed that these alternatives to banned herbicides were marketed at higher prices due to the higher demand from farmers arising from the shortage of herbicide products.

The majority (65%) of maize farmers in all the maize-based cropping systems used post-plant herbicides (Figures 7 & 8). Small-scale farmers used simple implements such as the hoe to control weeds during crop growth while large-scale farmers opted for market-available herbicides (Figure 7). Topramezone (Clio®) and Nicosulfuron (Topaz®), which are herbicides recommended by the Department of Agriculture (DOA, 2018) were the most widely used post-plant herbicides (Figure 8) for maize in the NCP. The KII revealed that the cost of chemical weeding by using Nicosulfuron was LKR 26,400 (approx. USD 88) per ha. Though Pendimethalin (mitosis disruptor; Rao, 2005) was also recommended as a post-plant herbicide for maize cultivation (DOA, 2018), it was not used by any farmer in the study sample or no evidence was available from KIIs and FGDs. This is mainly because mechanical land preparation makes the land free from weeds that emerged at the sowing stage and the availability of other effective post-emergence herbicides in the open market. Baghestani *et al*. (2006) reported that the application of Nicosulfuron successfully controlled weeds and resulted in the highest maize yield next to the weed free check. Gitsopoulos *et al*. (2010) also reported that the post emergence application of Topramezone at 2-4, 4-6 and 6-8 leaf stages of maize is effective in weed control.

Results from this study also showed that the use of herbicides is higher during the *Yala* season than the *Maha* season (Figure 89), because the occurrence of weeds is greater during *Yala* compared to *Maha*. This could be due to less frequent rainfall and irregular irrigation in *Yala* seasons (Malaviarachchi *et al*., 2016), creating and alternate wetting and drying condition supporting the weed growth better than in *Maha* seasons.

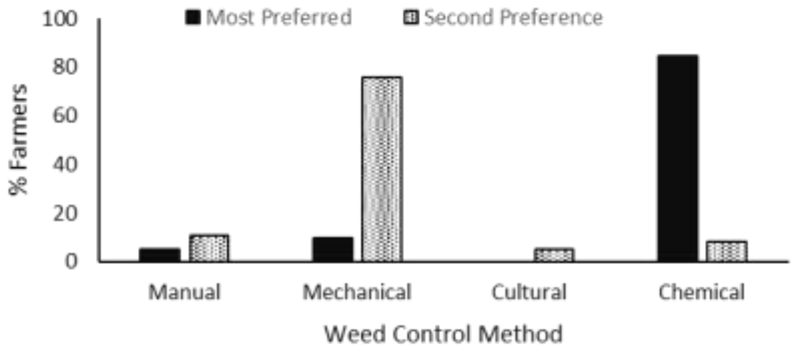

Figure 7. Best post-plant weed control method as perceived by the maize farmers in the North Central Province of Sri Lanka

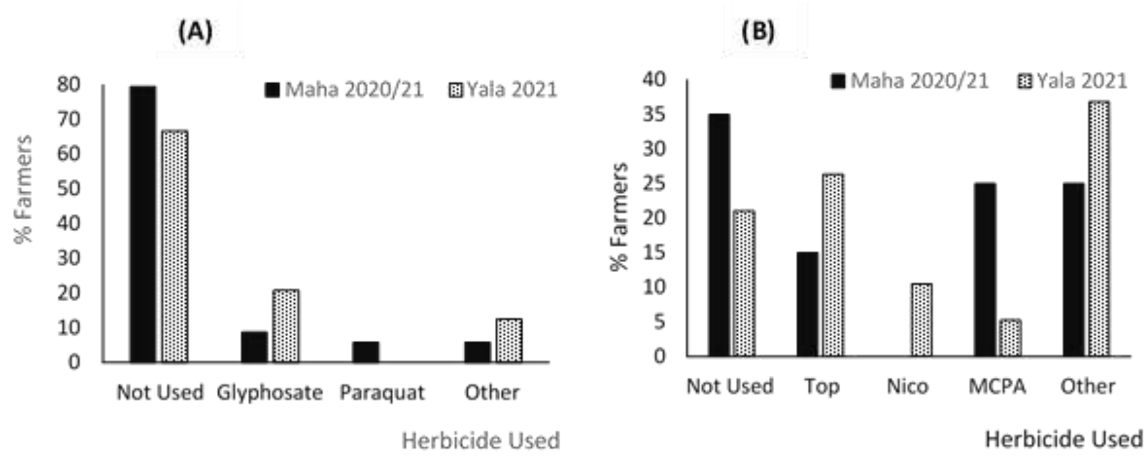

Figure 8. (A) Pre-plant and (B) post-plant herbicides used in maize cultivation (Top = Topramazone, Nico = Nicosulfuron, MCPA = 2-methyl-4-chlorophenoxyacetic acid). Note: Paraquat is a herbicide banned in Sri Lanka since 2014. Glyphosate was only allowed to be used for tea and rubber cultivation during the survey period.

The RUMM comprised more than 75% of maize cultivation in the NCP where farmers managed pre-plant weeding through primary land preparation by using four-wheel tractors mounted with a disk plough, followed by secondary land preparation using harrows and tine tillers. The survey and field monitoring confirmed that these maize farmers used post-plant herbicides, namely, Topramezone, or Nicosulfuron as a single application 10-15 days after sowing (DAS). Soon after chemical weeding they applied chemical fertilizer mixture containing Urea 225 kg/ha, Triple Super Phosphate 100 kg/ha, and Muriate of Potash 50 Kg/ha (DOA, 2018).

Farmers who practiced LPMM occasionally used pre-plant herbicides such as Glyphosate. However, the majority (92%) of farmers mechanically managed pre-plant weeds. Some used simple tools such as hoes, while some others used post-plant herbicides such as Topramezone or Nicosulfuron. Weed management in ACMM and CFMM was also similar to the LPMM. However, weed management in HGMP was done manually using hoes.

Farmers' perception and behaviour on herbicide usage for weed control in maize

In the study sample, about 23% of farmers practiced tank mixing of herbicides for pre-plant and post-plant weed control (Figure 9), a practice not recommended in Sri Lanka (Herath *et al.,* 2017). Table 3 shows that 25 respondent farmers (52%) were satisfied with the level of weed control in maize achieved without tank mixing herbicides. Among those who practiced tank mixing, five farmers (11%) were dissatisfied with the level of weed control achieved (Table 3). However, there was no significant association (p=0.4279) between tank mixing and farmer satisfaction on the level of weed control. The results suggest that tank mixing of herbicides did not improve weed control for most farmers (63%) despite the farmer's claim of better control. FGDs and KIIs also suggested that the average cost of herbicides for farmers practicing tank mixing herbicides, was 2.7-fold higher (LKR 17,862 per ha; approx. USD 59.70) compared to using a single herbicide formulation. Tank mixing showed no significant association (P>0.05) with label information (Table 3) indicating a higher likelihood of herbicide misuse, as reported by Rother (2018).

Some farmers (40%) had access to banned chemicals, while 23% had access to Glyphosate products (Figure 9) and 17% had access to other unregistered herbicide products that are not registered in Sri Lanka, as indicated previously. Marambe and Herath (2020) noted that the herbicide ban in Sri Lanka has opened avenues for the entry of smuggled products without quality control significantly increasing the cost of production of farmers. Maize production and productivity saw a drastic decline in 2022 (DCS, 2022), due to the ban on chemical fertilizers during from May to November 2021. However, KIIs and FGDs confirmed that farmers were willing to purchase smuggled herbicides at higher prices due to their herbicidal efficacy, encouraging some dealers to smuggle and sell unregistered chemical products in Sri Lanka.

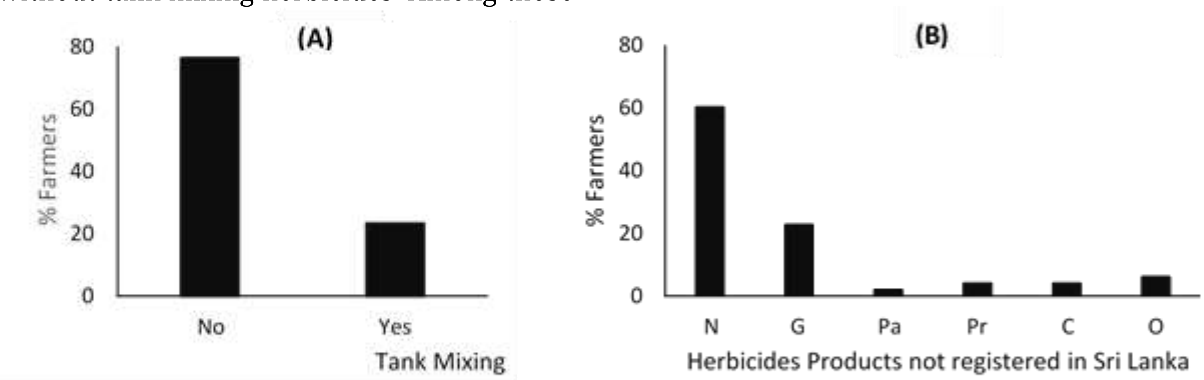

Figure 9. Tank mixing of herbicides (A) and use of chemical products that are not registered in Sri Lanka (B); N - Not Used, G - Glyphosate, Pa - Paraquat, Pr - Propanil, C - Carbofuran, O - Other

Table 3. Chi-square two-way table of tank mixing vs satisfaction on own weed control, Use of Label information and Herbicide application time of the day

Tank Mixing	Satisfaction on Own Weed Control*			
	No	Yes		
No	12 (25%)	25 (52%)		
Yes	5 (11%)	6 (12%)		
	Use of Label Information**			
Tank Mixing	Strictly Follow	Useful	Do not Bother	
No	11 (28%)	2 (5%)	26 (67%)	
Yes	0 (0%)	0 (0%)	12 (100%)	
	Herbicide Application Time**			
Tank Mixing	Morning	Noon	Evening	Any
No	23 (62%)	2 (5%)	8 (22%)	4 (11%)
Yes	11 (100%)	0 (0%)	0 (0%)	0 (0%)

*Values in the parenthesis are each event percentages; **The values in the parenthesis are row percentages

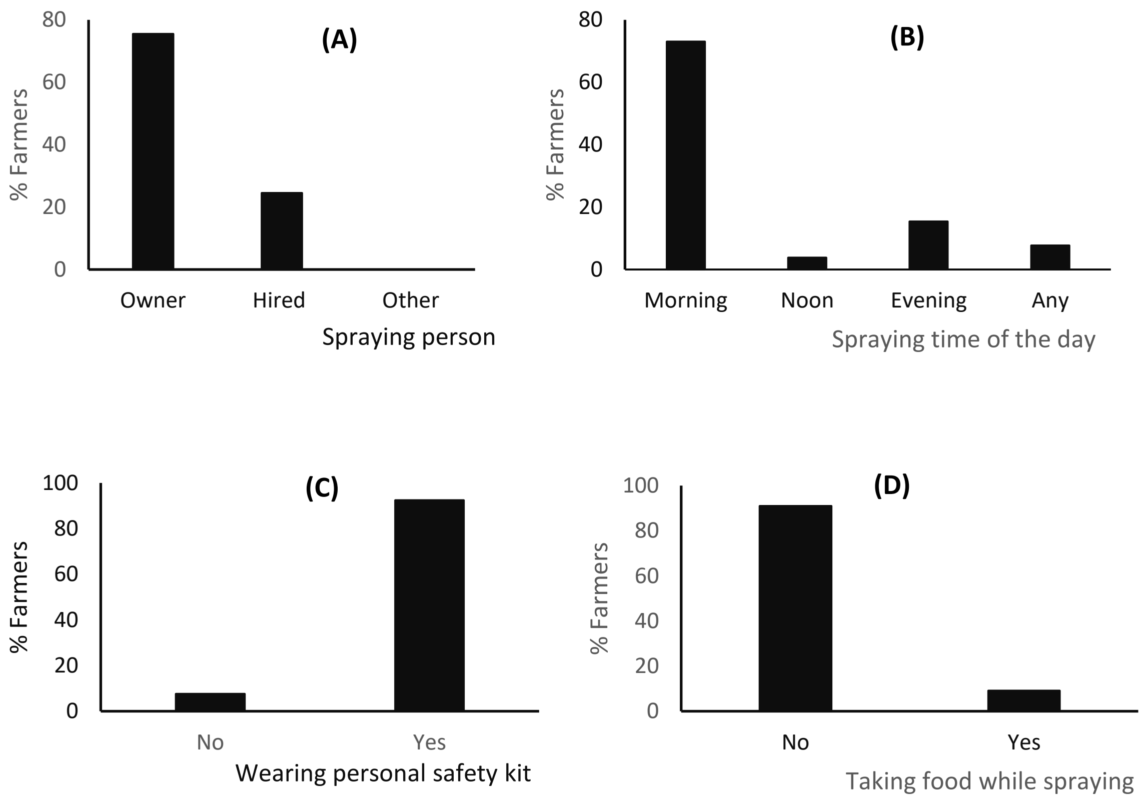

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Figure 10. (A) Person spraying herbicides, and (B) Spraying time of the day for maize, (C&D) Safety concerns related to spraying of herbicides for maize

About 28% of farmers in the study sample have strictly followed the label instructions, though only 5% perceived that the label information is useful, and 67% were not concerned of the label information (Table 3) and they applied herbicides based on their past experience. Out of the study sample, 71% of the farmers applied herbicides in the morning (Figure 10) in the absence of the dew factor, which indicates the proper understanding on the correct timing during the day for herbicide application to achieve efficient weed control as explained by Parween and Jan (2019). Absorption of herbicides to the leaf interior is efficient when the plant leaves are wet. As a result, application of herbicides in the morning is preferred and recommended. During noon and afternoon, leaf surfaces are dry and leaf burning could occur as a result of drying off of herbicides on the leaf surfaces leading to less absorption (Zhou, 1997).

About 92% followed safety precautions such as wearing personal protective kits and 91% were careful not to take food while spraying herbicides (Figure 10). This indicates that Sri Lankan maize farmers are aware and follow safety precautions and application guidelines of herbicides. Stadlinger *et al*. (2011) reported that though the majority of small-holder farmers in Tanzania consider the importance of following safety instructions, about 68-79% did not use protective gear during application of pesticides.

CONCLUSION

The rainfed upland maize monoculture (RUMM) and lowland paddy-based maize monoculture (LPMM) were the two major maize-based cropping systems in the NCP. RUMM represents more than 75% of maize cultivated in the NCP. There is potential to practice maize-animal integration to further improve land productivity. Maize farming in the NCP is highly mechanized, while 61% cultivating 2 to 10 ha of the crop. Family-labour (68%) is the main source of labour used in maize cultivation with about 68% of respondents undertaking full-time maize farming. Maize farming earns a net return of US$ 383 to US$ 1,000 per ha depending on the cropping system. Younger farmers are better educated on maize farming than elderly farmers. However, the ageing farming population in the NCP is a constraint as there is a lower tendency for the younger generation to take up maize farming.

Weeds are the main biological constraint to maize farming in the NCP. Perennial grasses such as *Megathyrsus maximus* and broad-leaf weeds such as *Lantana camara* and *Ocimum sanctum* have become dominant in maize cultivation in this province. Meanwhile, *M. maximus*, *Cyperus rotundus* (a perennial sedge) and *Euphorbia heterophylla* (an annual broadleaf) have become dominant in the lowland paddy-based maize monoculture cropping system (LPMM). Hence, weeds are considered one of the main constraints to maize production in the NCP.

Weed control in maize cultivation is achieved using herbicides particularly by large-scale commercial enterprises. Small farmers make significant efforts to control weeds incurring a significant cost (manual weeding using hoe costs 33% more than chemical weeding), which increases the cost of maize production. Many maize farmers use machinery for land preparation, indirectly leading to pre-plant weed control while a few even use pre-plant herbicides that are prohibited in Sri Lanka during the time of survey (e.g. Paraquat and Glyphosate) but are freely available in the open market. Post-plant weed control in maize is mainly achieved using the recommended herbicides, namely, Topramezone (Clio®) and Nicosulfuron (Topaz®). About 52% of respondent farmers achieved successful weed control without tank mixing these herbicides. However, 23% of farmers in the study sample practiced tank mixing of herbicides, which is not recommended by the DoA, Sri Lanka. The majority adopted safety measures including personal protection tools during spraying. However further efforts are needed to educate farmers on the correct use of herbicides in maize cultivation in Sri Lanka.

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