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EXPLOITING FODDER AND NUTRITIVE VALUE OF *ALTERNANTHERA PHILOXEROIDES* (ALLIGATOR WEED) AT DIFFERENT TIMES OF HARVEST: A POTENTIAL FODDER WEED

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Abstract

Invasive weed species dominate crop fields, forages, rangelands and pastures, thus, it is important to determine their nutritive value. Two year field study was aimed to explore nutritive value of quickly spreading invasive weed *Alternanthera philoxeroides* fodder at five harvest times including 28 days after emergence (DAE), 42 DAE, 56 DAE, 70 DAE and 120 DAE. Maximum fresh and dry matter yield of single cut fodder was 22.9-27.7 and 4.8-5.1 t ha^{-1}, respectively. The range of nitrogen (N), phosphorus (P), potassium (K), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), ash and fat contents in whole plant fodder except roots were 1.8-2.3%, 1.5-2.0%, 1.6-2.1%, 5.9-9.2 mg kg^{-1}, 39.8-99.9 mg kg^{-1}, 18.5-31.4 mg kg^{-1},34.4-64.5 mg kg^{-1}, 15.1-29.8% and 2.3-3.6%, respectively. Acid detergent fiber (ADF), neutral detergent fiber (NDF) and crude protein contents were ranging 13.0-17.9% and 23.3-38.9% and 10.2-14.2%, respectively. The total phenolic contents were 52-87 ug g^{-1}. Keeping in view the nutritive quality, digestibility and fodder yield, 70 DAE was the best time of harvest. *Alternanthera philoxeroides* possess nutritive value comparable to that of alfalfa, sorghum and maize. In addition, potential for multi cutting, positive response to climate change, vigorous growth under stresses and all type of habitats ensure its potential as new fodder species.

Key words: Alligator weed, Climate change, Micronutrients, Non-chemical weed control, Weeds as fodder.

Introduction

Alternanthera philoxeroides (Mart.) Griseb, (alligator weed), a fast spreading broad-leaved invasive weed, is adopted to diverse types of agro-ecological conditions including tropic, subtropics and temperate both in aquatic and terrestrial environments (Julien & Stanley, 1999; Abbas *et al.,* 2017). It was originated to northeastern Argentina, but now has become a common weed of major crops, field banks, road sides and uncultivated areas worldwide (Tanveer *et al.,* 2013). In Pakistan, it has become a troublesome weed in various summer season crops including rice, maize, cotton and sugarcane causing yield losses ranging from 24-45% (Mehmood *et al.,* 2018; Tanveer *et al.,* 2018). Fast and prostrate growth habit, certain physio-biological features like propagation through vegetative parts, phenotypic plasticity, wide adaptability, potential to grow under stress conditions, absence of natural enemies, strong allelopathic potential and its positive response to global warming are major reasons for its successful invasion (Bassett, 2009; Abbas *et al.,* 2017; Shi & Fu, 2017). Various types of phytotoxic compounds have been identified in this weed which have strong inhibitory effects on crop plants and weed species (Abbas *et al.,* 2016). Chemical weed control options to manage this weed have been suggested by various workers (Willingham *et al.,* 2015). However, difficult translocation of herbicide compound in underground or underwater storage tissues of *A. philoxeroides* make its chemical control less efficient (Hofstra & Champion, 2010). Furthermore, the challenges to herbicide use like herbicide resistance, herbicides residues on food products, the effect on grazing livestock, negative effects on environmental and aquatic flora to control this weed in aquatic habitat demand alternative strategies to manage this weed.

Alternanthera philoxeroides potentially attack crop fields, fodder and pastures, thus, the need is to determine the excellence and nutritive value of this weed before deciding about control options. Use of weed plants as fodder is one of the non-chemical, eco-friendly and sustainable alternatives to chemical weed control with additional benefits of valuable fodder for livestock. By turning weeds into forage, farmers can raise more animals with less money. In the scenario of increasing demands of fresh forage, identification of potential forage weed can play a vital role to fulfill the nutritional demands of livestock without additional cost to grow fodder. The ability of this weed to grow under diverse conditions (aquatic, semi-aquatic and terrestrial) can provide a sustainable fodder alternative in the areas having unpredictable rainfall (Khan *et al.,* 2009; Chen *et al.,* 2013). Furthermore, it regrows the same way as pasture species, it was noted that after cutting the top of *A. philoxeroides*, the remaining branches produced more buds, and when buds cutting were done, the branches below them produced more branches. *Alternanthera philoxeroides* fodder is easily available in fodder limited months of the year like May-June and Oct-Nov. It grows itself easily by vegetative parts or seeds, so we use it as fodder that might not otherwise have been useful. Recent studies have explored the suitability of various weed species as fodder and their nutritive values for animals, many weed species showed nutritional values and digestibility even more than common fodders due to higher level of protein and leaf-stem ratio (Khan *et al.,* 2013; Tozer *et al.,* 2015).

In forage production, harvest time is an important factor as it influences the fodder yield, macro and micro-nutrients status, crude protein and phenolic contents (Bumb *et al.,* 2016; Komainda *et al.,* 2018). Normally, maturity increases fiber concentration while decrease digestibility. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) traits of fiber contents study can be used to predict digestibility and relative feed value, while the intake ability is determined through NDF (Ball *et al.,* 2001; Hackmann *et al.,* 2008). Each plant species has a specific time of harvest to produce a high yield of quality fodder. For example, for most of the sorghum cultivars, physiological maturity was the best harvest time to achieve high yield and fodder quality, early stages produced less yield and quality (Atis *et al.,* 2012). Keeping in view these facts, it is important to determine the potential of *A. philoxeroides* for forage and its nutritive value for livestock.

To the best of our knowledge very rare studies have been conducted yet to explore the fodder and nutritive values of fast-spreading invasive (Abbas *et al.,* 2017) weed *A. philoxeroides*. Therefore, this study was conducted under field conditions for consecutive two years to determine the forage value of this weed at different times of harvests.

Materials and Methods

Experimental site: An experiment was conducted during two consecutive years 2011 and 2012 in a field naturally infested with a dense stand of *A. philoxeroides* at the research area of University of Agriculture, Faisalabad (31.44º N, latitude and 73.07º E, longitude), Punjab, Pakistan. Soil texture was sandy loam having 0.48% organic matter and 7.8 pH. The soil N, P and K contents were 0.051-0.054%, 12.8-13.2 and 127-131ppm in 2011 and 2012, respectively. During both years' weather data about monthly temperature (minimum and maximum), rainfall, average relative humidity and daily sunshine were obtained from AgroMet Observatory, Department of Crop Physiology, UAF (Table 1).

Experimental detail: Experiment comprised of five treatments i.e., *A. philoxeroides* harvesting 28 days after emergence (DAE), 42 DAE, 56 DAE, 70 DAE and 120DAE. It was laid out in RCBD with four replications having net plot size 6 m x 1m. The experimental field was cultivated 2 times at field capacity with a mechanical cultivator each time followed by planking. The applied dose of N and P was 150 kg ha^{-1} and 90 kg ha^{-1}, respectively. Phosphorus was applied at field bed preparation whereas nitrogen in three different splits. First split of N was applied at the last operation of land preparation whereas the second and third split was applied 25-30 days and 45-50 days after emergence, respectively. The field had been irrigated once a week and in total 19 irrigations were done for a full growth period.

Data collection and analysis: The data regarding fresh and dry biomass was determined by collecting samples from 1.0 m × 1.0 m area from three different randomly selected locations of each plot. For each time of harvest whole above-ground weed plant parts were collected and for the next harvesting interval other plants were harvested. Oven-dried samples were ground. For determination of N, Jackson (1962) method was used, while P contents were determined by using the vanadate-molybdate spectrophotometric procedure (Jones *et al.,* 1991). Potassium contents determination was done by using flame photometer (Chapman & Pratt, 1961). Atomic absorption spectrophotometer method was used to determine quantity of micronutrients including Fe, Mn, Zn and Cu (Jones *et al.,* 1991). Total soluble phenolics were determined as described by Randhir and Shetty (2005) and were expressed as gallic acid equivalents. The collected data of all parameters were subjected to analysis of variance (ANOVA) for the randomized complete block design by using computer software statistix 8.1 (Statistix, 2006). The significance was tested by a variance ratio (i.e. F-value) at 5% level of probability (Steel *et al.,* 1997). The least significant difference test was used for comparing the treatment means. Parameters that shown non-significant year effect, data were pooled before statistical analyses.

Results

***Alternanthera philoxeroides* fodder yield:** Fodder yield of *A. philoxeroides* showed significant differences at different times of harvest during both years (Table 2). Data showed that with the increase in harvesting time fresh and dry fodder yield was also enhanced. Harvesting at 120 DAE caused more *A. philoxeroides* fresh and dry fodder yield of 22.9-27.8 t ha^{-1} and 4.8-5.1 t ha^{-1} of single cut during 2011 and 2012, respectively. Harvesting of *A. philoxeroides* 28 DAE resulted in fresh biomass of 7.3-9.2 t ha^{-1} and dry fodder yield of 1.35-1.5 t ha^{-1} of a single cut. Comparatively more fodder yield in the second year of study was due to more monthly rainfall and other more optimal weather conditions (Rashid & Rasul, 2011) (Table 1).

NPK contents (%) of *A. philoxeroides* fodder: The statistically significant effect of various harvesting intervals of *A. philoxeroides* on its N, P and K contents (%) was observed for both years (Table 3). The *A. philoxeroides* harvested at 28 DAE showed maximum N, P and K contents (2.3, 2.0 and 2.1%, respectively). A gradual decrease in N, P and K contents (%) of *A. philoxeroides* with an increase in harvesting period was observed from 28 to 120 DAE. The minimum N, P, and K contents (1.8, 1.5, and 1.6%, respectively) of *A. philoxeroides* were calculated at 120 DAE.

Copper, iron, zinc and manganese contents (mg kg^{-1}) in *A. philoxeroides* fodder: The Cu, Fe, Zn and Mn contents in *A. philoxeroides* fodder harvested at different stage ranged from 5.9-9.2, 39.8-99.9, 18.5-31.4 and 34.4-64.5 mg kg^{-1}, respectively during both years of study (Table 4). The plant age has a significant effect on Cu, Fe, Zn and Mn contents, increasing days after emergence caused a decrease in nutrient contents. The maximum Cu, Fe, Zn and Mn contents (9.2-8.9, 97.2-99.9, 31.4 and 64.5, respectively) were observed in *A. philoxeroides* harvest at 28 DAE, while the plants harvested at 120 DAE showed minimum Cu, Fe, Zn and Mn contents (5.9-6.2, 40.1, 18.5 and 34.4, respectively). Copper and iron contents of *A. philoxeroides* were significantly different during both years, however for Zn and Mn year effect was non-significant.

Table 1. Metrological data during the course of presented studies.

Months	Average temperature (°C)				Total rainfall (mm)		Average relative humidity (%)		Daily sunshine (h)	
	Maximum		Minimum							
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
June	39.1	41.0	25.9	26.1	78.4	85.1	55.2	65.2	9.4	9.4
July	35.2	34.6	25.9	27.5	118.2	135.3	70.5	65.2	9.0	8.9
August	33.9	34.0	25.6	26.0	92.3	102.5	75.1	80.2	5.5	6.0
September	33.2	32.7	23.8	24.1	155.2	180.2	76.2	84.7	7.0	7.8
October	31.8	32.2	16.9	18.7	0.4	5.1	59.9	60.2	7.5	7.6
November	28.1	27.5	13.3	12.5	0.0	4.2	61.3	55.4	8.4	8.7

Source: AgroMet Observatory, Department of Crop Physiology, UAF

Table 2. Green fodder yield and dry matter yield (kg ha^{-1}) of *A. Philoxeroides* single cut at different times of harvest

Time of harvest (days after emergence)	Fresh fodder yield (t ha^{-1})		Dry matter yield (t ha^{-1})	
	2011	2012	2011	2012
28	7.26 e	9.19 e	1.35 d	1.52 d
42	12.26 d	13.58 d	2.17 c	2.82 d
56	13.01 c	14.16 c	2.51 b	3.10 c
70	19.40 b	19.88 b	3.55 a	3.54 b
120	22.93 a	27.79 a	4.88 a	5.12 a
LSD 5%	339.76	232.31	81.26	108.17
Year effect	11169.0 b	15316.0 a	1770.00 b	2494.90 a
LSD	**186.46**		**38.32**	

Means not sharing the same letter in a column differ significantly according to LSD test ($p \leq 0.05$)

Table 3. Nitrogen, phosphorous and potassium contents of *A. philoxeroides* fodder at different times of harvest.

Time of harvest (days after emergence)	N (%)		P (%)		K (%)	
	2011	2012	2011	2012	2011	2012
28	2.28 a	2.26 a	2.12 a	1.96 a	2.18 a	2.12 a
42	2.19 b	2.10 b	1.93 b	1.78 b	1.95 b	2.00 b
56	2.12 c	1.93 c	1.79 c	1.69 c	1.84 c	1.88 c
70	1.96 d	1.78 d	1.68 d	1.62 d	1.72 d	1.77 d
120	1.79 e	1.63 e	1.56 e	1.48 e	1.59 e	1.68 e
LSD 5%	0.055	0.132	0.102	0.062	0.071	0.060
Year effect	2.07 a	1.94 b	1.81 a	1.70 b	1.85 b	1.89 a
LSD	**0.042**		**0.034**		**0.023**	

Means not sharing the same letter in a column differ significantly according to LSD test ($p \leq 0.05$)

Table 4. Micro nutrient contents of *A. philoxeroides* fodder at different times of harvest.

Time of harvest (days after emergence)	Cu (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})	Mn (mg kg^{-1})
	2011	2012	2011	2012	Mean	Mean
28	9.18 a	8.85 a	99.93 a	97.15 a	31.41 a	64.46 a
42	8.48 b	7.95 b	77.81 b	82.86 b	27.40 b	56.80 b
56	7.91 c	7.25 c	66.34 c	71.89 c	24.40 c	49.61 c
70	7.24 d	6.65 d	54.42 d	61.43 d	22.26 c	42.29 d
120	6.22 e	5.93 e	40.86 e	39.77e	18.54 d	34.36 e
LSD 5%	0.137	0.122	1.760	4.093	2.27	2.97
Year effect	7.80 a	7.32 b	67.87 b	70.62 a	-	--
LSD	**0.073**		**2.36**		**-**	**-**

Means not sharing the same letter in a column differ significantly according to LSD test ($p \leq 0.05$)

Table 5. Ash, Fat, ADF and NDF of *A. philoxeroides* at different times of harvest.

Time of harvest (days after emergence)	Ash (%)		Fat (%)		ADF (%)		NDF (%)	
	2011	2012	2011	2012	2011	2012	2011	2012
28	27.75 a	29.78 a	3.50 a	3.62 a	11.58 e	12.95 e	23.28 e	26.35 e
42	25.52 b	27.59 b	3.15 b	3.22 b	13.64 d	17.75 d	27.55 d	29.78 d
56	20.15 c	20.35 c	2.80 c	2.82 c	14.85 c	16.28 c	29.85 c	32.88 c
70	17.22 d	19.44 d	2.50 d	2.62 d	15.96 b	17.82 b	32.42 b	35.85 b
120	15.18 e	15.28 e	2.26 e	2.38 e	17.91 a	19.22 a	36.16 a	38.92 a
LSD 5%	0.060	0.042	0.160	0.043	0.320	0.136	0.110	0.031
Year effect	21.16 b	22.49 a	2.84 b	2.93 a	14.79 b	16.20 a	29.85 b	32.76 a
LSD	**0.021**		**0.047**		**0.101**		**0.031**	

Means not sharing the same letter in a column differ significantly according to LSD test ($p \leq 0.05$)

Table 6. Crude protein and total phenolics in *A. philoxeroides* fodder at different times of harvest.

Time of harvest (days after emergence)	Crude protein (%)	
	2011	2012
28	14.22 a	14.10 a
42	13.66 b	13.14 b
56	13.22 c	12.08 c
70	12.24 d	11.13 d
120	11.21 e	10.18 e
LSD 5%	0.344	0.824
Year effect	12.91 a	12.12 b
LSD	**0.262**	

Means not sharing the same letter in a column differ significantly according to LSD test ($p \leq 0.05$)

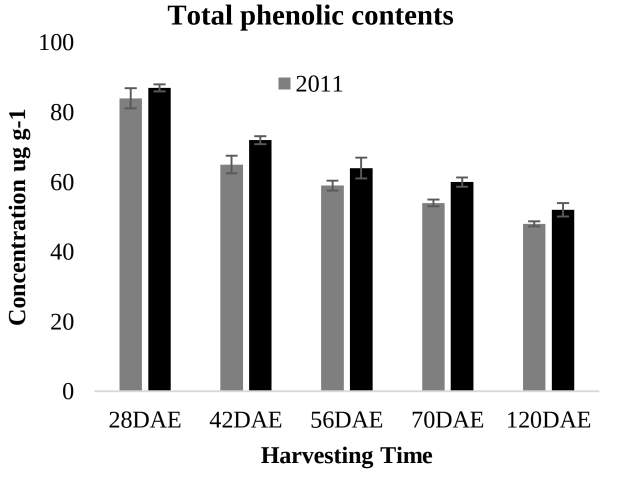

Fig. 1. Total phenolics in *A. philoxeroides* fodder at different times of harvest. DAE = Days after emergence.

Ash, fat and fiber contents (%) in *A. philoxeroides* fodder: The ash, fat, acid detergent fiber (ADF) and neutral detergent fiber (NDF) contents in *A. philoxeroides* fodder ranged from 15.1-29.8, 2.3-3.6, 13.0-17.9, 23.3-38.9%, respectively (Table 5). Harvesting times had a significant effect on ash, fat, ADF and NDF of *A. philoxeroides* fodder during both years of study. The increasing time of harvest after weed emergence caused a significant decrease in ash and fat contents, while ADF and NDF contents increased with an increase in time of harvest. Maximum ash and fiber contents (30 and 3.6%, respectively) were achieved in *A. philoxeroides* fodder harvested 28 DAE, whereas the *A. philoxeroides* harvested 120 DAE showed minimum ash and fat contents (15.2 and 2.3%, respectively). However, in the case of ADF and NDF, the maximum ADF and NDF contents (19.2 and 38.9, respectively) were achieved in *A. Philoxeroides* fodder harvest 120 DAE, while minimum ADF and NDF contents (11.5 and 26.3, respectively) were obtained at 28 DAE.

Crude protein (%) and total phenolics (ug g^{-1}) contents in *A. philoxeroides* fodder: The crude protein contents in *A. philoxeroides* fodder harvest at different times ranged from 10.2-14.2%. The harvest times have a significant influence on crude protein contents, increasing harvest time after emergence caused a decrease in crude protein contents (Table 6). The highest protein contents (14.2%) were recorded in *A. philoxeroides* fodder harvested at 28 DAE, while minimum crude protein contents (10.2%) were found in fodder harvested 120 DAE. Total phenolic contents ranged from 52-87 ug g^{-1} were significantly decreased with an increase in time of harvest. *Alternanthera philoxeroides* harvested 120 DAE showed minimum (48 ug g^{-1}) phenolic contents (Fig. 1).

Among the different times of harvest 70 DAE was the best time to harvest this weed for good nutrition, digestibility and fodder yield. The fresh and dry fodder yield per cut at 70 DAE was 19.4-19.9 t $ha^{-1}$and 3.6-3.7 t ha^{-1}, respectively. The N, P, Cu, Fe, Zn, Mn, ash and fat contents at 70 DAE were 1.9-1.8%, 1.7-1.6%, 1.7-1.8%, 6.6-7.2 mg kg^{-1}, 54.4-61.4 mg kg^{-1}, 22.3 mg kg^{-1}, 42.3 mg kg^{-1}, 17.2-19.4% and 2.5-2.6% for both year of study, respectively. Acid detergent fiber (ADF), neutral detergent fiber (NDF) and crude protein contents ranged 15.9-17.8% and 32.4-35.8% and 11.2-12.3%, respectively.

Discussion

The invasive weed *Alternanthera philoxeroides*is is a fast-growing and easily available weed under diversified ecological conditions and can be used as a good source of fodder. An increase in dry matter yield with long-standing *A. philoxeroides* period might be due to the additional time advantage by *A. philoxeroides*to continue its subsequent growth and development resulting in more photosynthates and better biomass accumulation. The fresh and dry fodder yield of *A. philoxeroides* is more than common weed species like canada thistle and barnyard grass, the more fodder yield was due to higher photosynthetic activity and adaptability of this weed (Chen *et al.,* 2013). The yield per cut of this weed is more than rhodes grass (*Chloris gayana*. L. Kunth) that yield up to 24.5and 6.69 t ha^{-1} fresh fodder and dry fodder yield, respectively (Arshad *et al.,* 2016). Increase in fodder yield with advanced plant maturity has been reported for fodder species (Atis *et al.*, 2012).

The N, P and K concentrations found in *A. philoxeroides* are in line to major forage species e.g. alfalfa and maize (Islam *et al.*, 2010; Samuil *et al.,* 2012). The percent P measured in this weed is more than alfalfa (0.25-0.70%), however, K concentration is slightly less than alfalfa fodder (2.5-3.0%) (Samuil *et al.,* 2012). The N, P and K percentage in *A. philoxeroides* was more than maize fodder, which showed 1.5-1.9%, 0.15-0.23% and 2.2-2.4% of N, P and K, respectively (Islam *et al.,* 2010). The efficient photosynthetic activity and ability to grow well at changing moisture conditions helped this weed to uptake more nutrients from the soil (Chen *et al.*, 2013). Micronutrients concentrations in forages is a major factor to determine fodder quality and their lacking can cause serious health disorder in livestock (Gupta *et al.*, 2001). Among micronutrients cations (Cu, Fe, Mn and Zn) are more common to determine fodder quality and have specific deficiency levels. For example, if the fodder has more than 5 mg kg^{-1} Cu, the Cu deficiency does not occur in animals (Gupta & Lipsett, 1981). In *A. philoxeroides* the Cu range is 5.9-9.2 mg kg^{-1}. The range of Fe, Zn and Mn in fodder required for healthy livestock is 35-50, 20-30 and 30-45 mg kg^{-1}, respectively (Gupta *et al.*, 2001). The micronutrient composition of *A. philoxeroides* is in the range of best quality fodder even fulfill the requirements of dairy cattle.

The ash contents found in *A. philoxeroides* (15.1-29.8%) are more than maize (7.51-9.36%). While ADF and NDF were less than maize fodder that normally contains 33.23-35.21% and 55.69-57.66% ADF and NDF, respectively (Islam *et al.*, 2010). An increase in ADF and NDF with advanced maturity of sorghum fodder has been reported by Atis *et al.,* (2012). Comparatively less ADF and NDF than other fodder crops showed its good quality and more digestibility for livestock.

The gradual decline in total phenolic contents with an increase in age of this weed is a good sign for its use as fodder because for increasing time to harvesting more fresh and dry fodder will be achieved**.** Phenolic contents affect the intake, growth and digestibility of fodder, higher phenolic contents are reported to cause a decrease in animal growth, protein digestibility and metabolism (Reed *et al.,* 1990).

Protein contents are an essential component in livestock diet, the crude protein contents of *A. philoxeroides* are found in rang of good quality fodder. The crude protein contents in alfalfa range from 12.3-15.7% (Samuil *et al.*, 2012). The normal ranges of crude protein in maize and sorghum fodders are 9.93-11.91% and 6.9-9.8%, respectively, which is less than *A. philoxeroides* (10.2-14.2%) (Islam *et al.*, 2010; Kumari *et al.,* 2016). Bosworth *et al.,* (1980) reported various weed species that had adequate crude protein contents for various livestock species. The decrease in crude protein contents with advanced plant maturity has been reported by Atis *et al.,* (2012), who demonstrated a significant reduction in protein of sorghum fodder with its maturity.

It has more photosynthetic activity than other native vegetation and has the potential to grow well under different moisture levels even water logged conditions (Chen *et al.,* 2013). In coming decades, possibly we will be more thankful for the weed plants in terms of nature sustainability and use them as fodder, rather than the ways to eliminate them. The present findings uncovered that this weed has great nutritive quality including macro nutrients, micro nutrients, fat and protein contents, even more than some common fodders like alfalfa, sorghum and maize (Islam *et al.,* 2010; Samuil *et al.,* 2012). The ADF and NDF were less than major fodder crops that showed its good quality and more digestibility fodder.

Conclusion

The present findings reveal that invasive weed *A. philoxeroides* can be used as quality fodder at any harvesting stage. However, 70 DAE is the best time of harvest to get higher fodder yield, nutrition and digestibility. The nutritive value of *A. philoxeroides* at different cuttings need to be determined to further explore its potential as fodder.

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