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Teosinte (*Euchlaena mexicana* L.) Seed Production: Effect of Sowing Date, Seed Rate and Cutting Management on Seed Yield

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Abstract: Teosinte (*Euchlaena mexicana* L.) is a popular herbage crop in Nepal. Although farmers produce teosinte seeds, management for maximizing seed yield is unknown. A study was undertaken to investigate teosinte seed yield in order to explore the seed production potential of teosinte for maximizing herbage yield. There were four different sowing dates (30 March, 30 April, 30 May and 30 June), four seed rates (20, 40, 60 and 80 kgha^{-1}) and three herbage cuttings (nil, once at 45 days after sowing (DAS), twice at 45 and 75 DAS) arranged in a split-split plot design. In both years, the highest seed yield was obtained from the two earliest sowings because they had taller plants, more tillers, a higher leaf area index (LAI) and more cobs per plant, ears per cob and seeds per ear than later sown plants. In 2017, seed yield did not differ among the seed rates because of adverse climatic conditions; however, in 2018 the two lower seed rates out yielded the two highest seed rates. Cutting twice significantly reduced seed yield in both years; one cut did not reduce seed yield in 2017 but it did so in 2018. These results suggest teosinte seed crops should be sown early at a seed rate between 20 to 40 kgha^{-1}. An economic analysis indicated that the traditional farmer practice of taking one herbage cut from their seed crop would not affect the gross margin.

Keywords: crop gross margin; herbage cutting; leaf area index; Nepal; seed yield components

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1. Introduction

Teosinte (Figure 1A,B) is a very popular herbage for dairy farming in tropical areas [1] because of its high herbage yield and quality, its versatility and its ability to rapidly regrow after cutting [2]. It can produce more herbage than maize (*Zea mays* L.) in both non-stress and stress conditions [3], and in Nepal it can be cultivated from sea level to an elevation of 1500 m above sea level [4]. Nepalese farmers use a "cut and carry" system to feed dairy cows and buffalo, and green herbage yields are between 3.5 and 4.5 tha^{-1} [5]. Teosinte was an important component of summer herbage crops for the Nepal Government's "Forage Mission" program, which ran from 2013 to 2016, to mitigate the national deficit of green herbage for dairy animals; in 2018 the area under teosinte crops in Nepal was 27,232 ha [6]. Thus, this research aims to assess teosinte's seed production potential under different management practices, which would potentially increase herbage production and ultimately, livestock productivity. Although several studies have investigated the impact of crop management on teosinte herbage production in Nepal [1,2,7], there have been no reports on impacts on teosinte seed production from Nepal. Teosinte is reported to be a direct ancestor of maize [8,9], but whether management for maize seed production is also be applicable to teosinte seed production is unknown. Being a short day plant, its seed production requires the full season of growth. Seed production is much more impacted by variation in sowing date as sub-optimum temperature during early sowing affects field emergence and crop early growth and development, resulting in poor seed set, forced maturation and low seed yield [10]. With delayed sowing, growth occurs under higher temperatures, with simultaneous reductions in period of growing cycles, which affects the cumulative incident photosynthetically active radiation (PAR) at silking, significantly reducing the seed yield [11]. A planting window therefore provides the necessary information to the farmers to maximize yields and profit from seed production [12]. Thus, sowing date should be timed to avoid the damaging effects of high temperatures at flowering and during seed set, which have a negative impact on seed yield [13]. For maize, optimum sowing date will depend on site, environment and hybrid, but for locations with high (>30 °C) summer temperatures, sowing date should be timed to avoid the damaging impact of high temperature at flowering and at seed set, which has a negative effect on seed yield [14,15]. Optimum seed rates are those that allow maximum interception of photosynthetically active radiation per unit area: a few plants do not allow maximum usage of resources whereas too many plants results in competition for resources.

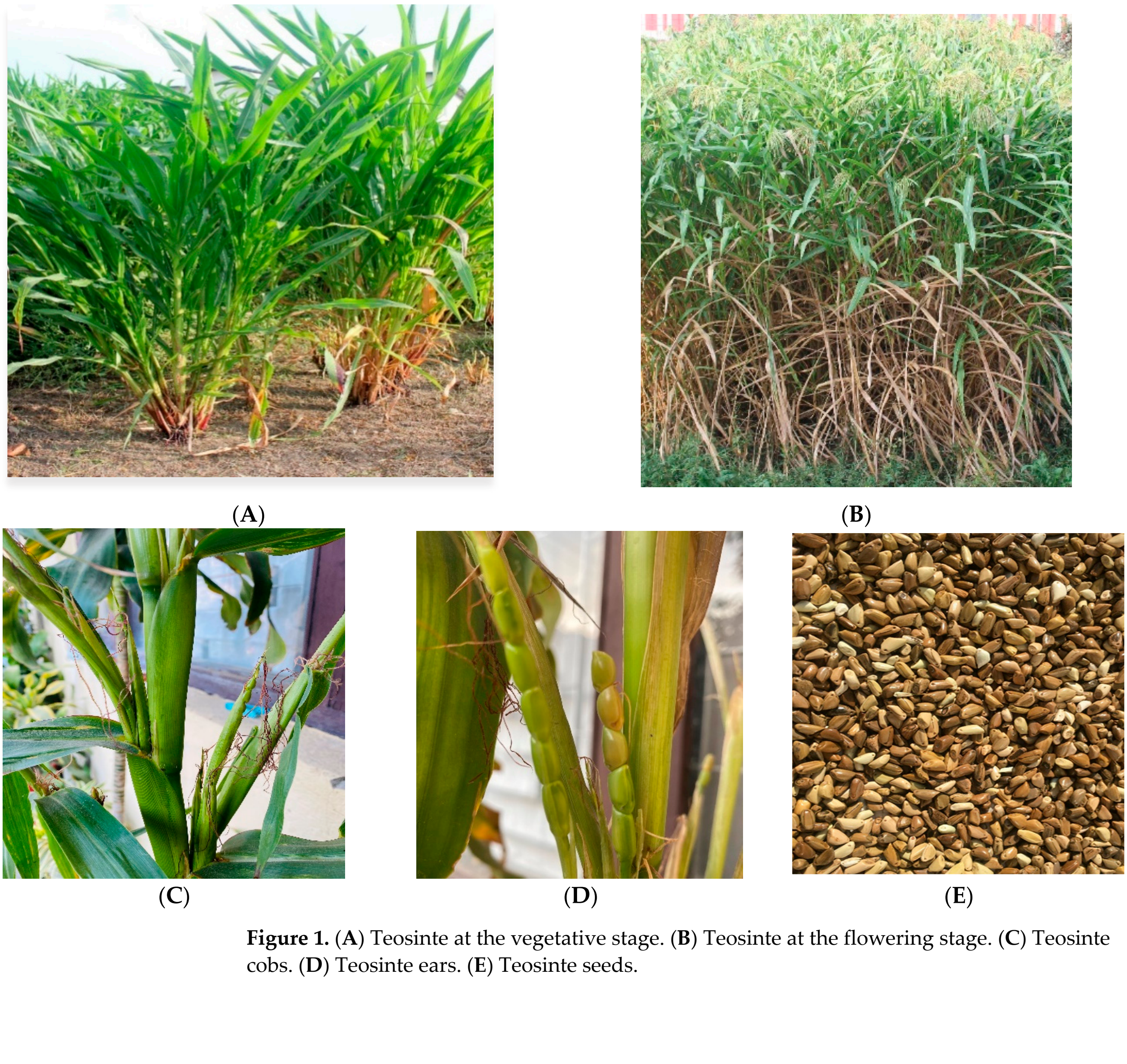

Figure 1. (**A**) Teosinte at the vegetative stage. (**B**) Teosinte at the flowering stage. (**C**) Teosinte cobs. (**D**) Teosinte ears. (**E**) Teosinte seeds.

Both situations reduce seed yield [16,17]. Taking one or more herbage cuts from a seed crop can reduce seed yield [14] but taking a single cut during vegetative growth may increase seed yield [18] by stimulating tiller production and therefore providing a larger photosynthetic area for reproductive growth [19]. Nepalese farmers are accustomed to taking one or more herbage cuts from their teosinte seed crops [20].

This study explored three hypotheses. The first was that teosinte would produce the highest seed yield from an early season sowing. The second was that a seed rate of 40 $kgha^{-1}$ or less would provide an optimum plant population for seed production. The third was that while taking one herbage cut may decrease seed yield, it would not negatively affect crop gross margin for the farmers.

2. Materials and Methods

2.1. Field Experiments

The experiments were conducted from March to December in 2017 and 2018. The fields were at the National Cattle Research Program (NCRP), Nepal Agricultural Research Council (NARC), farm at Rampur, Chitwan, Nepal. This is in the central region of Nepal at 27°40′ N latitude and 84°35′ E longitude with an altitude of 228 m above sea level.

The land had been cropped in cereals in the previous seasons. Stubble was ploughed in and then the fields were harrowed to prepare a seed bed. The soil was slightly acidic (pH 6.7) light textured sandy loam. In each year, nitrogen (urea, 60 $kgha^{-1}$), phosphate (diammonium phosphate, 60 $kgha^{-1}$) and potassium (muriate of potash, 40 $kgha^{-1}$) were applied by hand as a basal dressing before harrowing.

In both years, a split-split plot experimental design was used with sowing date as the main plot, seed rate as the sub plots and cutting as the sub-sub plots. Plot size was 3.2 × 2 m. The time of sowing plots was allocated randomly within the trial area. Untreated seeds of teosinte cv Sirsa [21] were hand sown on 30 March followed by three consecutive sowings at 30-day intervals. In 2018, the June sowing was omitted. Sowing depth was 5 cm, and row to row spacing was 40 cm. Seed sowing rates were 20, 40, 60 and 80 kg ha^{-1}, which resulted in between plant spacing within the row of 10, 5, 3.5 and 2.5 cm, respectively. Plots were flood irrigated seven days after the first sowing, but for other sowings rainfall meant that irrigation was not required. Plots were hand weeded as required, and a further 60 $kgha^{-1}$ urea was hand broadcasted just before flowering. For the cutting treatments, plant stems were removed 15 cm above ground level at 45 DAS and 75 DAS to allow the regeneration of the plant and cut material to be removed from the field to determine herbage yield.

2.2. Climate Data

Rainfall, temperature and humidity data were obtained from a weather station situated 100 m from the trial site. Chitwan has a humid, subtropical climate with a cool winter (8–21 °C) and hot summer (14–34 °C). Annual rainfall averaged 1333 mm, with a distinct monsoon period (>75% of annual rainfall) from mid-June to mid-September.

2.3. Plant Attributes

Ten days after seedling emergence, ten plants from the central row of each plot were selected at random and tagged at the stem base. From these ten plants, the following data were recorded. Plant height (cm) was measured from the base of the plant to the node of the flag leaf once tasselling was completed. Tillers per plant were counted just prior to seed harvest. Final tillers were calculated by adding the primary and secondary tillers on each plant. Leaf area Index (LAI) was calculated by measuring the length and width of a mature, fully open and physiologically active leaf. It was calculated using the method of Musa and Usman [22].

$$LA = L \times W \times K$$

where, LA: Leaf area (cm^2); L: Length of leaf (cm); W: Width of leaf (cm); K: Factor (0.75). LAI = Leaf area (cm^2)/Land area per plant (cm^2).

2.4. Seed Yield and Its Components

From the tagged plants, the number of cobs per plant (Figure 1C), ears per cob (Figure 1D) and seeds per ear were counted. From these data, the number of seeds per plant was calculated. Cobs were hand harvested when seed moisture content had reached 25–27%, as determined by a moisture meter (Wiley 55, Farmcomp Oy, Tuusula, Finland). Cobs were harvested from the main stem and from secondary tillers present along the internodes of the main stem. Cobs were then hand threshed, seeds were cleaned by sieving and final seed yields (Figure 1E) were corrected to 14% seed moisture content.

2.5. Economic Analysis

The impact of cutting for herbage on the seed crop was studied where the following assumptions were made to calculate the gross margin. One kilogram of teosinte herbage will increase milk yield by 0.67% [20], which is equivalent to 0.044 l $animal^{-1}$ day^{-1}. The average milk yield was 6.5 l $animal^{-1}$ day^{-1} and farm gate price was Nepalese rupee (Rs) 60 per litre [4]. The value of green herbage fed was Rs 6 kg^{-1} [4]. All the costs incurred from preparing land for sowing to seed crop harvesting, including cost of seed and fertilizer, land rent and labour, were recorded. Seed sale price was Rs 110 kg^{-1} [4].

2.6. Statistical Analysis

Statistical analyses of data were performed using Genstat software 19th Edition [23]. Analysis of variance (ANOVA) was used to compare the means of sowing date, seed rate and cutting management on seed yield and associated yield components of teosinte and the interactions among the factors was performed using General Linear Model (GLM) of Genstat 19th Edition. Least significant difference (LSD 5, 1 and 0.1 percent) was used to compare means of treatments. The interaction between the treatment factors was calculated and least significant interaction at 5% was used to test interaction significance. The relationship between the sowing date, seed rate and cutting management with the seed yield components was determined by regression analysis.

3. Results

3.1. Main Effect Means of Sowing Date, Seed Rate and Cutting Management on Vegetative Plant Components of Teosinte

Plant height for the first three sowing dates was significantly higher ($p < 0.005$) than for the June sowing in 2017. In 2018, the earlier two sowings had significantly taller plants than the third sowing ($p = 0.005$). In both 2017 and 2018, cutting significantly reduced plant height ($p < 0.001$) (Table 1). There was a significant negative correlation ($R^2 = 0.93$) between sowing dates and plant height and between cutting management and plant height because plant height decreased as the sowing date was delayed and as the cutting frequency was increased. There was a significant interaction between sowing date and cutting management for final plant height in 2017 ($p < 0.001$) (Table 1) because of the impact of cutting on reducing plant height for the June sowing. In 2018, there was a significant interaction between seed rate and cutting management because cutting reduced final plant height irrespective of seed rates ($p < 0.05$) (Table 1).

Table 1. Main effect means of sowing date, seed rate and cutting management on plant properties of teosinte in 2017 and 2018 at NCRP, Chitwan, Nepal.

Main Effect Means of:	**Final Plant Height (cm)**		**Final Tiller Number Per Plant**		**LAI**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**
Sowing date (SD)						
30-Mar	340 ^{a}	364 ^{a}	8.1 ^{a}	6.6 ^{a}	3.2 ^{a}	3.5 ^{a}
30-Apr	331 ^{a}	348 ^{a}	7.8 ^{a}	5.4 ^{b}	3.0 ^{a}	3.2 ^{a}
30-May	321 ^{a}	319 ^{b}	6.1 ^{b}	4.2 ^{c}	1.3 ^{b}	2.0 ^{b}
30-Jun	279 ^{b}	-	5.5 ^{b}	-	1.2 ^{b}	-
Linear contrast *p* value	0.002	0.005	<0.001	<0.001	<0.001	0.001
LSD (5%)	32	25	0.9	0.6	0.6	0.6
CV%	6.2	4.2	8.0	6.3	16	12.4
Seed rate (SR)						
20 kg ha^{-1}	325 ^{a}	351 ^{a}	6.9 ^{a}	5.3 ^{a}	2.4 ^{a}	3.3 ^{a}
40 kg ha^{-1}	317 ^{a}	335 ^{a}	6.8 ^{a}	5.5 ^{a}	2.2 ^{b}	3.2 ^{a}
60 kg ha^{-1}	317 ^{a}	346 ^{a}	7.1 ^{a}	5.5 ^{a}	2.2 ^{b}	2.9 ^{a}
80 kg ha^{-1}	313 ^{a}	342 ^{a}	6.7 ^{a}	5.3 ^{a}	2.0 ^{b}	2.2 ^{b}
Linear contrast *p* value	0.669	0.484	0.797	0.818	0.001	<0.001
LSD (5%)	32	17	0.76	0.4	0.2	0.6
CV%	14	6	15.6	8.6	14.0	23.4
Cut management (CM)						
No cut	341 ^{a}	373 ^{a}	8.1 ^{a}	5.5 ^{a}	2.5 ^{a}	3.5 ^{a}
One cut	313 ^{b}	332 ^{b}	7.0 ^{b}	5.6 ^{a}	2.1 ^{b}	2.6 ^{b}
Two cut	300 ^{b}	325 ^{b}	5.4 ^{c}	5.1 ^{b}	2.0 ^{b}	2.5 ^{b}
Linear contrast *p* value	<0.001	<0.001	<0.001	0.03	<0.001	<0.001
LSD (5%)	22	16	0.5	0.3	0.2	0.4
CV%	20	12	21.1	15.2	25.3	30.8
Significance of interactions of linear contrasts (*p* value)						
SD (lin) × SR (lin)	0.900	0.237	0.400	0.892	0.018	<0.001
SD (lin) × CM (lin)	<0.001	0.073	0.633	0.735	0.143	0.842
SR (lin) × CM (lin)	0.772	0.037	0.431	0.611	0.045	0.092
SD (lin) × SR (lin) × CM (lin)	0.681	0.387	0.587	0.543	0.175	0.911

LAI = Leaf Area Index; LSD = Least Significant Difference; CV = Coefficient of Variation; - = Not Applicable. Lettering has been assigned using the unrestricted LSD procedure; means with no letters in common (in the same column) are significantly different at the 5% level ($p < 0.05$). SD = sowing date; SR = seed rate; CM = cutting management.

In 2017, tiller numbers at the first and second sowing were significantly higher than at the third and fourth sowing, but in 2018 tiller number was significantly lower for the second and third sowings, respectively ($p < 0.001$). Seed rate had no significant on tiller number in either year. In 2017, cutting significantly reduced the tiller numbers per plant ($p < 0.001$). In 2018, double cutting reduced tiller numbers ($p < 0.05$) (Table 1). There was a negative correlation between sowing dates and tiller numbers ($R^2 = 0.88$) and a significant negative correlation between cutting management and tiller number ($R^2 = 0.95$) ($p < 0.05$).

LAI for the March and April sowings was significantly greater than for the later sowings in both years ($p < 0.001$) (Table 1). The lowest seed rate had the highest LAI in 2017 ($p = 0.001$) but not in 2018. Uncut plants had a significantly higher LAI than cut plants in both years ($p < 0.001$) (Table 1). A significant negative correlation between sowing date and LAI ($R^2 = 0.94$) and seed rate and LAI ($R^2 = 0.93$) occurred, but there was a negative correlation between cutting management and LAI ($R^2 = 0.81$) ($p > 0.05$).

In 2017, a significant interaction ($p < 0.05$) between sowing date and seed rate occurred for LAI because LAI was higher for the two earliest sowing dates, and a significant interaction between seed rate and cutting management occurred because uncut plants recorded highest LAI for the lowest seed rate. In 2018, a significant interaction between sowing date and seed rate occurred ($p < 0.001$) because the earliest two sowings recorded the highest LAI at the lowest seed rate (Table 1).

3.2. Main Effect Means of Sowing Date, Seed Rate and Cutting Management on Reproductive Yield Components of Teosinte

Cob numbers per plant and seeds per ear did not differ between the March and April sowing or between the April and May sowing in either year ($p < 0.01$). The highest number of cobs per plant was recorded from the lowest seed rate in 2018 (Table 2). In 2017 the three lowest seed rates and in 2018 the two lowest seed rates had the highest seeds per ear ($p < 0.005$) (Table 2). Only double cut plants had significantly fewer cobs per plant and seeds per ear ($p < 0.001$) in 2017, but in 2018, uncut plants produced a significantly higher number of cobs per plant and seeds per ear than cut plants ($p < 0.001$) (Table 2). A significant negative correlation occurred between sowing date and cobs per plant ($R^2 = 0.98$) and between cutting management and cobs per plant ($R^2 = 0.92$) because cob number decreased as sowing date was delayed. In 2017, a significant interaction was recorded between sowing date and cutting management because the June sowing produced the least number of cobs from the twice cut plants ($p < 0.05$) and also between sowing date and seed rate in 2018 because the March sowing produced the highest cobs per plant at the lowest seed rate ($p < 0.05$). There was also a significant interaction between seed rate and cutting management because uncut plants produced the highest number of cobs per plant from the lowest seed rate ($p < 0.01$). Similarly, an interaction among sowing date, seed rate and cutting management occurred because uncut plants from the March sowing produced the highest number of cobs per plant at the lowest seed rate ($p < 0.05$) (Table 2). There was a significant interaction between sowing date and cutting management for seeds per ear in 2017 ($p < 0.01$) and sowing date and seed rate in 2018 ($p < 0.01$) (Table 2)

Table 2. Main effect means of sowing date, seed rate and cutting management for teosinte seed yield and yield components in 2017 and 2018 at NCRP, Chitwan, Nepal.

Main Effect Means of:	Cobs per Plant		Ears per Cob		Seeds per Ear		Total Seed Yield kg ha^{-1}	
	2017	2018	2017	2018	2017	2018	2017	2018
Sowing date (SD)								
30-Mar	11.5 ^{a}	8.4 ^{a}	6.8 ^{a}	6.3 ^{a}	5.0 ^{a}	4.8 ^{a}	4233 ^{a}	3791 ^{a}
30-Apr	10.1 ^{ab}	7.8 ^{ab}	6.0 ^{a}	5.8 ^{a}	4.6 ^{ab}	4.7 ^{ab}	3440 ^{a}	3054 ^{a}
30-May	8.7 ^{b}	7.0 ^{b}	5.1 ^{b}	4.4 ^{b}	4.4 ^{b}	4.3 ^{b}	1778 ^{b}	1618 ^{b}
30-Jun	6.3 ^{c}	-	4.0 ^{c}	-	3.0 ^{c}	-	998 ^{b}	-
Linear contrast p value	<0.001	0.007	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (5%)	1.6	0.9	0.8	0.6	0.4	0.5	924	859
CV%	11.2	6.5	9.3	6.9	6.3	5.8	23	19
Seed rate (SR)								
20 kg ha^{-1}	9.2 ^{a}	8.6 ^{a}	5.3 ^{a}	6.0 ^{a}	4.2 ^{ab}	4.9 ^{a}	2605 ^{ab}	3475 ^{a}
40 kg ha^{-1}	9.4 ^{a}	8.0 ^{b}	5.7 ^{a}	5.5 ^{ab}	4.4 ^{a}	4.6 ^{ab}	2628 ^{ab}	3287 ^{a}
60 kg ha^{-1}	9.3 ^{a}	7.5 ^{b}	5.4 ^{a}	5.5 ^{ab}	4.3 ^{ab}	4.4 ^{b}	2850 ^{a}	2772 ^{b}
80 kg ha^{-1}	8.6 ^{a}	6.8 ^{c}	5.5 ^{a}	5.0 ^{b}	4.1 ^{b}	4.5 ^{b}	2366 ^{b}	1751 ^{c}
Linear contrast p value	0.153	<0.001	0.793	0.001	0.191	<0.005	0.439	<0.001
LSD (5%)	0.9	0.5	0.4	0.5	0.2	0.3	406	430
CV%	14	7.2	10.7	10.9	7.7	7.7	22	18
Cut management (CM)								
No cut	10.3 ^{a}	8.3 ^{a}	5.8 ^{a}	6.2 ^{a}	4.7 ^{a}	5.1 ^{a}	3092 ^{a}	3311 ^{a}
One cut	9.8 ^{a}	7.7 ^{b}	5.7 ^{a}	5.7 ^{b}	4.6 ^{a}	4.8 ^{b}	2725 ^{a}	2850 ^{b}

Two cut	7.3 [b]	7.1 [c]	5.0 [b]	4.6 [c]	3.5 [b]	4.0 [c]	2019 [b]	2303 [c]
Linear contrast *p* value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (5%)	0.7	0.4	0.3	0.4	0.2	0.2	406	227
CV%	20.7	11.8	17	18.6	11.1	13	44	20
Significance of interactions of linear contrasts (*p* value)								
SD (lin) × SR (lin)	0.575	0.022	0.722	0.508	0.261	0.016	0.054	0.820
SD (lin) ×CM (lin)	0.016	0.639	<0.001	0.007	<0.001	0.393	0.046	<0.001
SR (lin) × CM (lin)	0.66	0.010	0.844	0.087	0.088	0.954	0.781	0.632
SD (lin) × SR (lin) × CM (lin)	0.851	0.021	0.530	0.279	0.306	0.613	0.446	0.140

LSD = Least Significant Difference; CV = Coefficient of Variation. Lettering has been assigned using the unrestricted LSD procedure; means with no letters in common (in the same column) are significantly different at the 5% level ($p < 0.05$). SD = sowing date; SR = seed rate; CM = cut management.

Ears per cob and seed yield were greatest for the earliest two sowings in 2017 ($p < 0.001$) and 2018 ($p < 0.05$). In 2018, the highest seed rate had fewer ears per cob ($p < 0.005$) and the lowest seed yield ($p < 0.001$) (Table 2). In 2017, ears per cob and seed yield did not differ between uncut and once cut plants. In 2018, ears per cob and seed yield decreased significantly with each cutting ($p < 0.001$) (Table 2). A significant interaction between sowing date and cutting management occurred in both 2017 ($p < 0.001$) and in 2018 ($p < 0.05$) because the uncut plants produced significantly more ears per cob from the March and April sowings (Table 2). There was a significant correlation between sowing dates and seed yield ($R^2 = 0.97$) ($p < 0.05$) and a negative correlation between cutting management and seed yield ($R^2 = 0.98$) ($p < 0.05$).

A significant interaction between sowing date and cutting management occurred in both 2017 ($p < 0.001$) and 2018 ($p < 0.05$) (Table 2). The interaction in 2017 was because the first two sowings produced the highest ears per cob in the uncut (and one cut) plants (Table 2) and in 2018 the uncut plants produced significantly more ears per cob from the March and April sowings (Table 2). For seed yield, there was a significant interaction between sowing date and cutting management in 2017 ($p < 0.001$) and 2018 ($p < 0.05$) because the March sowing produced the highest seed yield in uncut plants (Table 2).

3.3. Association of Vegetative and Reproductive Components with Seed Yield in Teosinte

For the different sowing dates, plant height, number of tillers, LAI and cobs per plant were the important contributors to determining the total seed yield of teosinte. Seed yield was positively correlated with plant height in 2017 and the relationship was statistically significant in 2018 ($p < 0.05$) (Figure 2A). Similarly, tiller number was significantly correlated with seed yield (Figure 2B) in 2017 ($p < 0.05$) and 2018 ($p < 0.01$). In both years, LAI was positively and significantly correlated with seed yield (Figure 2C). Cobs per plant were positively correlated with seed yield ($p < 0.05$) (Figure 2D). No statistically significant correlations between the yield components and seed rates were recorded. For cutting management, seed yield was significantly correlated with tiller number in 2018 ($p < 0.05$) but not in 2017 (Figure 2E), and cobs per plant, ears per cob and seeds per ear were all positively correlated with seed yield ($p < 0.05$) (data not presented).

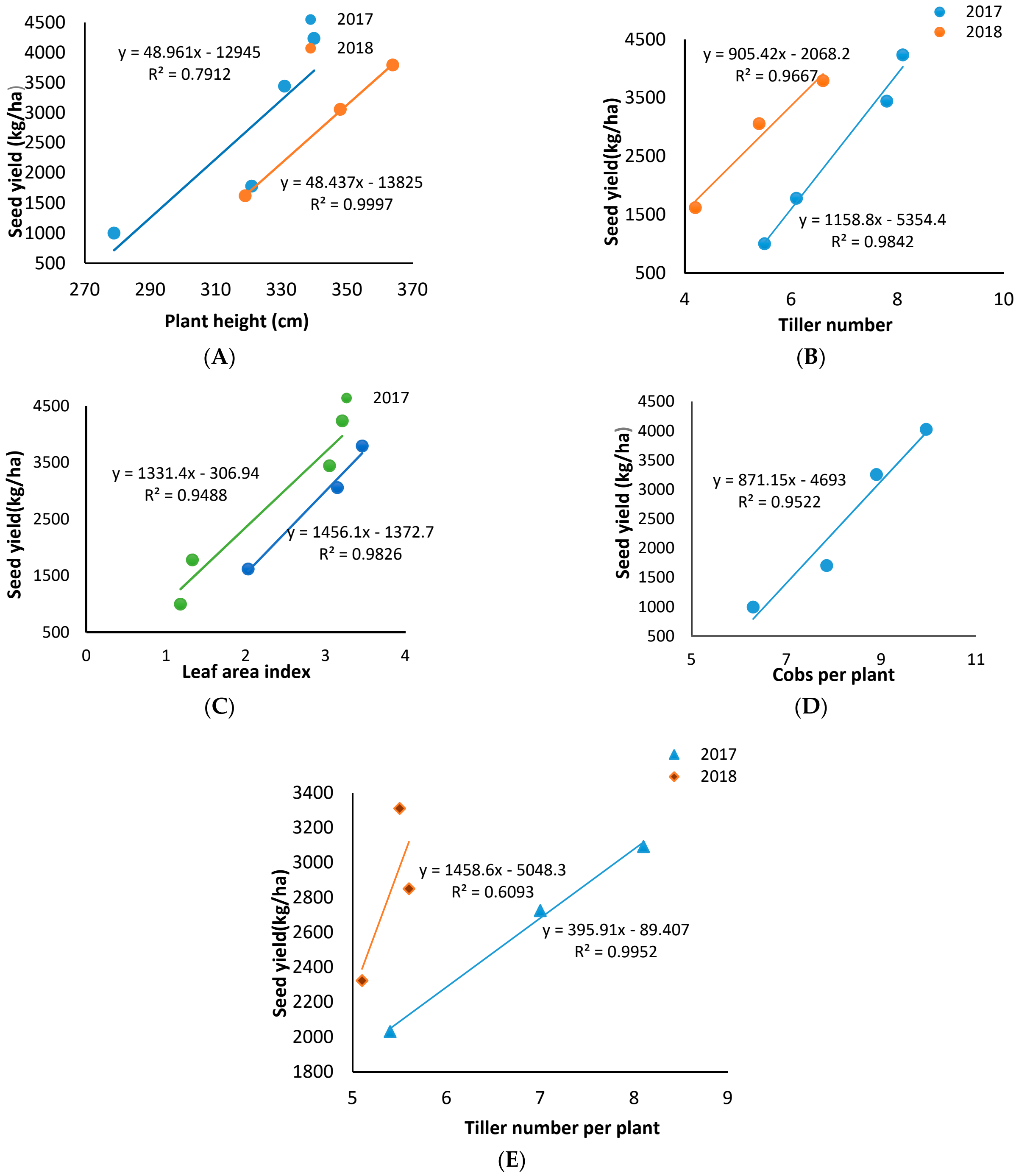

Figure 2. (**A**) Correlation between teosinte plant height and seed yield using main effect means of different sowing dates. (**B**) Correlation between teosinte tiller number and seed yield using main effect means of different sowing dates. (**C**) Correlation between teosinte leaf area index and seed yield using main effect means of different sowing dates. (**D**) Correlation between teosinte cobs per plant and seed yield using main effect means of different sowing dates (average mean of both years). (**E**) Correlation between teosinte tiller number and seed yield using main effect means of different cutting management. The circles, triangles and diamonds in different colours in figure A,B,C, and D are the mean values of seed yield with respect to plant height, tiller number, leaf area index, cobs per plant against sowing dates and in figure E they represent the mean value of seed yield with respect to tiller umber per plant against different cutting management.

3.4. Economic Analysis

Although both cutting treatments in 2018 and double cutting in 2017 significantly ($p < 0.05$) reduced the income from seed production, the additional income from milk produced after feeding the cut teosinte to milking animals compensated for the farmer, to the extent that the gross return for the no cut and one cut treatments did not differ in either season (Table 3). However, the seed income loss following double cutting could not be recovered by the extra milk production (Table 3). The extra costs involved with cutting twice meant that the gross margin was significantly ($p < 0.05$) lower than that of the no cut and one cut treatments for which the gross margin did not differ.

Table 3. Effect of cutting management on the gross margin for a teosinte seed crop in 2017 and 2018 at NCRP, Chitwan, Nepal (NRs. = Nepalese rupees).

Cutting Management	Income from Milk (Rs ha^{-1})		Income from Seed (Rs ha^{-1})		Gross Return (Rs ha^{-1})		Total Cost (Rs ha^{-1})		Gross Margin (Rs ha^{-1})	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
No cut	-	-	310,198 a	364,156 a	310,198 a	364,156 a	68,979 c	72,376 c	241,219 a	291,780 a
One cut	29,763 b	36,033 b	272,494 a	313,470 b	317,139 a	367,520 a	75,371 b	80,107 b	241,768 a	287,413 a
Double cut	42,563 a	52,652 a	201,486 b	253,379 c	265,765 b	332,357 b	76,715 a	82,808 a	189,050 b	249,549 b
Linear contrast *p* value	<0.001	<0.001	<0.001	<0.001	0.035	0.002	<0.001	<0.001	0.011	0.002
LSD (5%)	3036	4104	42,634	24,958	41161	26,880	1167	1281	40,047	25,896
CV%	16	22	46	20	39	19	5	4	51	23

4. Discussion

Sanjyal [20] showed that as teosinte sowing was delayed, the number of days from first emergence to first flowering averaged 168,143 and 114 days for the March, April and May sowings and was 87 days for the June sowing in 2017. For the latter, the plants had the least time to accumulate assimilates, [24,25], and plant height was lower than for the three earlier sowings in that year. Although plant height did not differ among the March, April and May sowings in 2017, it was slightly reduced for the May sowing in 2018, possibly because higher temperature in the first month after emergence accelerated development but reduced biomass accumulation. Cutting reduced plant height in both years. The removal of vegetative material reduced the ability of the plant to intercept light, which then reduced photosynthetic capability [26]. Although vegetative regrowth occurred, it was insufficient to attain the height reached by noncut plants.

With the exception of the March and April sowings in 2017, tillers per plant deceased as sowing date was delayed, again reflecting the number of days available for vegetative growth. A longer growing period with no moisture stress allows greater capture of photosynthetically active radiation, resulting in increased tiller production [27,28]. Similar tiller numbers for the first two sowings in 2017 were possibly because of similar temperatures for each month, but this cannot be confirmed. Seed rates had no effect on tillers per plant (or plant height) in either season, suggesting that the competition provided by the highest of those plant densities was not sufficient to reduce the supply of assimilates to individual plants for vegetative growth. In 2017, both cuts reduced tiller number, but in 2018 only the double cutting did so. Cutting reduces light interception by the plant which interrupts photosynthesis and hinders the supply of assimilates to the root system for support of regrowth of tillers [5]. However, if light becomes available to tiller buds after cutting, and temperature favours tiller regrowth [29], then rapid new tiller production can occur. This could explain why in 2018 the once cut plants produced as many tillers as the noncut plants.

LAI did not differ between the March and April sowings in either year but was reduced for the subsequent sowings. Again, this can be explained by the longer time for vegetative growth for the earlier sowings that provided more opportunity for radiation interception and leaf growth [12]. LAI in both years was higher for the lowest seed rate, a response also reported by Crozier et al. [30] in maize. This was possibly because as plant density increased, shading by leaves increased, reducing light interception [31]. Cutting reduced LAI by reducing the plant's ability to produce new tillers and leaves [32].

Significant interactions were recorded for plant height (sowing date and cutting management in 2017; seed rate and cutting management in 2018) and for LAI (sowing date and seed rate in both years; seed rate and cutting management in 2017). Early sowing allowed more time for cut plants to regrow and achieve a greater height than later sown cut plants. If the lowest seed rate allowed greater light interception, this also would allow the earlier sown plants more time to better utilize that intercepted light, because of greater LAI, and to regrow after cutting.

The advantages of early sowing for vegetative growth were also apparent for reproductive growth, as the two earlier sowings produced the highest numbers of cobs per plant, ears per cob, seeds per ear and therefore seed yield. For the different sowing dates, plant height, tiller number and LAI were all significantly correlated with seed yield, allowing higher solar radiation interception and an increased availability of stored and current assimilates to support reproductive growth, as reported in maize by Banotra et al. [33].

All the seed yield components tended to decrease as sowing date was delayed, a result consistent with that previously reported for maize [34]. However, seed yield did not differ for the two earlier sowings. Better solar radiation interception by a larger leaf area [33], resulting in increasing assimilate supply over an extended growing season, results in increased seed yield for early sown crops [33,35]. The variation in cob and ear numbers between the two seasons is possibly explained by difference in rainfall, with 2018 being much drier during reproductive growth than 2017. Seed rate had no effect on cobs per plant, ears per cob, seeds per ear or seed yield in 2017, but in 2018 these tended to decrease with increasing plant density. In the 2017 season, a high wind and heavy rain event during vegetative growth broke main stems and tillers with the observed damage appearing to be greater in the high-density plots. This may have reduced the impact of crowding stress [36] on reproductive growth. The 2018 results indicate that there was stress due to interplant competition for resources at the higher plant densities [37], which is likely to have decreased reproductive growth. As expected, double cutting resulted in insufficient time for plants to recover [38] and accumulate the assimilates required for reproductive growth, so that seed yield and all its components were significantly reduced in both seasons. However, for the single cut these reductions only occurred in 2018, probably because in 2017 the environment allowed more rapid vegetative regrowth after cutting.

Pariyar and Shrestha [21] reported that the average teosinte seed yield in Nepal ranged from 1000 to 1500 kg ha^{-1}, similar to the May and June sowings, but less than half of that achieved for the March sowings in both seasons. However, Pariyar and Shrestha [21] also noted that as a monsoon crop, teosinte was usually sown in June/July, and only when irrigation was available could it be sown in March/April. They did not comment on seed yield differences between the two sowing times.

The early sowing yields of 3000–4000 kg ha^{-1} were closer to the 1800–2340 kg ha^{-1} teosinte seed yields reported by Sallan and Ibrahim [39] from field experiments over two seasons in Egypt. These authors reported a plant height of around 150 cm, 7–9 tillers per plant and 10 cobs per plant. In Nepal cv. Sirsa grows to over 300 cm in height but has a similar number of tillers and cobs per plant as the unnamed Egyptian cultivar used by [39]. Very tall plants carrying cobs are susceptible to lodging/stem breakage following strong winds and create difficulties for seed harvest, which in Nepal is by hand [21]. The Egyptian yield component data suggest that selection for reduced plant height in Nepali teosinte would not negatively impact seed yield.

Farmers in Nepal have experience growing teosinte as a herbage crop for feeding milking animals, but for many growing a seed crop is a new experience [20]. Taking one herbage cut from a seed crop is common practice, but farmers are often tempted to take a second cut as well. Double cutting reduced seed yield by 30%, whereas a single cut reduced it by 12%, reducing the income from seed sales by 109,744 $Rsha^{-1}$ for the former and

44,195 Rs ha^{-1} for the latter. However, when the income from milk production was included in the gross return, only that for the double cut was significantly lower, and even though there were extra costs involved with cutting (labour), the gross margin did not differ between one cut and no cut. Taking one herbage cut from a teosinte seed crop can be recommended, at least for this site in Nepal.

5. Conclusions

The present study explored three hypotheses, all of which were supported. Early sowing produced the highest seed yield; when averaged across the two seasons, the 20 and 40 kgha^{-1} sowing rates out yielded the 60 and 80 kgha^{-1} sowing rates; and taking one herbage cut at 45 DAS would not reduce the crop gross margin for the farmers. Although these experiments were conducted at one site, the terrain and environment are typical of central/southern Nepal, and these seed crop management recommendations would therefore be widely applicable.

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