Determination of Optimal Seed Harvest Timing for *Panicum torridum* Based on Growing Degree Day Heat Unit Accumulation

Scott B. Lukas*, Joseph DeFrank and Orville C. Baldos

ABSTRACT

The native Hawaiian annual grass *Panicum torridum* Gaudich. (Torrid panicgrass) has been selected for development of seed production protocols to aid in re-vegetation efforts throughout Hawaii. The determination of harvest timing is an important factor needed to optimize mature seed yield. Numerous studies have detailed the difficulties associated with rapid seed shattering in grass seed production systems, as seen in *P. torridum*. The utilization of heat accumulation units as growing degree days (GDD) can be used to characterize mature seed development based on thermal time, thus providing a specific quantifiable harvest time to maximize seed yields. The objective of this study was to optimize mature seed harvest timing of *P. torridum* by creating a quantifiable heat accumulative unit (GDD) indicator value. Results indicated that maximum seed yield occurred when accumulated GDD values after anthesis initiation were 249 and 259 for August and January planting periods in Hawaii, respectively. In cases where GDD calculation is not practical, the recommended harvest time for maximum seed yield in *P. torridum* is 9 d after anthesis for August plantings, and 12 d for January planting, in Hawaii. This research can be utilized by restoration practitioners to maximize *P. torridum* seed harvesting, and the methods can be adopted for other seed production candidates.

INTRODUCTION

Panicum torridum Gaudich. (Torrid panicgrass) is an endemic grass in Hawaii, ranging from 10–60 cm in height, with velvety puberulant leaves. Distribution studies conducted in the year 1942 indicated that *P. torridum* is found on all Hawaiian Islands with sporadic distribution (Ripperton and Hosaka, 1942). In 1992, *P. torridum* was found to be a dominant species along the summit ridge of the Lehua islet on the remote island Niihau (Daehler and Baker, 2006). In Hawaii, annual grasses such as *P. torridum* normally emerge in April to May following the rainy season that lasts from November to January (G. Sakamoto, personal communication). *Panicum torridum* is found below 90 m elevation in zones that receive 50–100 cm of annual rainfall (Ripperton and Hosaka, 1942).

A critical stage in the production of agricultural crops is the correct timing of harvest to maximize yield and quality (Copeland, 1995; Russo, 1996; Bednarz et al., 2002). For seed crop production, ideally all seeds would mature uniformly

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at the same location on the plant and be ready for harvest at the same time. However, this seldom happens (McDonald and Copeland, 1997). *Panicum torridum* has been selected for development of seed production protocols to aid in early-stage re-vegetation efforts throughout Hawaii. The species has been chosen for re-vegetation purposes by conservation groups and botanists in Hawaii because of the rapid establishment and short seed production times. However, parameters for seed production are unknown. *Panicum torridum* seed appears to mature rapidly in an indeterminate pattern. Indeterminate maturation causes shedding of mature seeds on one portion of the inflorescence while other regions remain immature (McDonald and Copeland, 1997). In such cases, the timing of harvest is a compromise to enable the greatest yields of high quality mature seed while minimizing seed loss to shattering (Garcia-Diaz and Steiner, 2000). Numerous studies have detailed the difficulties associated with rapid seed shattering in grass seed production systems (Hides, 1987; Wang et al., 2006). In many grass species, seed harvesting is initiated after initial shedding begins, but delays in harvesting result in substantial seed losses (Pegler, 1976).

There are many factors known to influence flowering time in angiosperms, foremost of these are length of day (photoperiod) and temperature (Ellis et al., 1997; Blázquez et al., 2003; Karsai et al., 2008). The influences of flowering based on temperature and photoperiod relate to the accumulation of heat units. The degree day heat accumulation unit was developed by Réaumur in the year 1735 to describe the relationship between plant morphological development rate and temperature (Bonhomme, 2000). Plant growth and development have a closer correlation to thermal time than chronological time (Severino and Auld, 2014). The degree day unit or growing degree day (GDD) approach is a method widely used for quantification of thermal time (Shrestha et al., 2010). It is based on the assumption that growth ceases below a given temperature (base temperature), and that growth increases linearly in response to incremental temperature increases (Yang et al., 1995). Relationships between GDD and rates of morphological development have been used to schedule management of warm season grasses (Mullahey et al., 1990; Sanderson and Wolf, 1995; Madakadze et al., 2003). GDD have been successfully used to characterize seed harvest production timing in the native Hawaiian grass *Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult. (Baldos, 2013).

It has been found that the linearity between development rate and temperature is only valuable for a relatively limited range of temperatures (Bonhomme, 2000), thus highlighting the importance of the base temperature (Yang et al., 1995). For tropical *Panicum* grasses, little or no growth is expected when temperatures are below 15; this threshold value is generally accepted as the base temperature for other tropical species (McWilliam, 1978; Baldos, 2013; Moreno et al., 2014).

Understanding more precise timing methods for the optimization of seed harvesting for *P. torridum* could enhance production capacity and minimize seed losses, which are especially important due to the rarity of this endemic species. The objective of this study was to optimize mature seed harvest timing of *P. torridum* by creating a quantifiable heat accumulative unit (GDD) indicator.

MATERIALS AND METHODS

Plant material

Panicum torridum seeds were sown in Sunshine mix #4 with mycorrhizae (Sun Gro Horticulture®, Agawam, Massachusetts) in 38 cell seedling trays (Landmark Plastic®, Akron, Ohio). Seedlings were identified as suitable for transplantation when root balls remained intact when extracted from seedling trays. This growth stage corresponded to 55 d (trial 1—August planting) and 75 d (trial 2—January planting) after direct seeding into tray cells. Fertilization and irrigation were provided as needed throughout the pre-transplantation period to maximize growth.

Experimental design

The experiment was designed as a randomized complete block with four replications. Two replicate experimental trials were conducted in the same experimental plots, separated temporally by 6 mon to test if the GDD predictions were accurate over two differing seasons. Trials 1 and 2 were initiated in August 2014 and January 2015, respectively. Each trial replicate consisted of a separate raised 3 × 3 m planting bed, filled with Tropical Blend compost (33% compost, 33% 1.5 cm black cinder, 33% screened soil, 11-52-0 fertilizer, pH 7.76; Hawaiian Earth Products™, Kapolei, Hawaii) with bed borders provided by 5 cm diameter white PVC pipe. *Panicum torridum* plants were planted in rows with a between row and in row spacing of 0.30 m, with border plants excluded from data sampling. Overhead irrigation was provided two times daily at 5:00 am and 12:00 pm for 15 min. Trials 1 and 2 irrigation volumes were measured to be 2100 L ha^{-1} min^{-1} and 2000 L ha^{-1} min^{-1}, respectively; these rates were maintained for all irrigation applications. During the second trial, cooler ambient temperatures imposed less moisture demand, resulting in reduced irrigation times from 15 to 12 min. Experimental plots were amended with 56 kg nitrogen ha^{-1} (formulation 21-4-7) 7 d before planting in both experimental trials. Preliminary research indicated the pre-emergence herbicide oxadiazon in a granular form applied at 4.48 kg ai ha^{-1} can be safely applied to *P. torridum* transplants without a reduction in biomass. In order to suppress weed growth during both experimental trials, oxadiazon at 4.48 kg ai ha^{-1} was applied to the soil 3 d after planting. Before the initiation of trial 2, a seed germination bioassay using *Cynodon dactylon* (L.) Pers. (bermudagrass) seeds confirmed that no residual herbicide had persisted from the previous experimental run.

Data collection

In both trials, data collection did not commence until 50% of the *P. torridum* population had initiated anthesis. Data collection consisted of sampling *P. torridum* seed heads at 3 d intervals beginning at the anthesis point. At each sample time, three dominant seed heads were removed from one randomly selected *P. torridum* plant in each of the four replications. Dominant seed heads consisted of the largest and most developed seed heads on each plant at the given sample interval. Sampling continued until *P. torridum* seeds were fully shed from the inflorescence, at which point data collection ceased. During both trials, 11 samples were taken in each replication, spanning a sampling period of 33 d. At each sampling time, seed heads from each plant were individually bagged and assessed for moisture content following constant oven moisture analysis techniques, as outlined by ISTA (ISTA, 2003).

Seed cleaning

At the end of the data collection period, seed heads (groups of 3 sampled) were processed to remove seeds from the inflorescence. Seeds were extracted and separated from dried, pulverized flower head tissues using two devices specifically designed for this purpose. The first step made use of a Westrup® LA-H brush machine fitted with a #14 mantle (1.0 × 1.0 mm square mesh) and medium nylon 0.5 mm brushes (Westrup® Inc., Plano, Texas). As the name implies, the brush machine presses the seed heads against a perforated metal cylinder, seeds are allowed to push through the cylinder and larger plant parts are retained within the cylinder. The brush machine was run at full power for 1 min with the front discharge door closed. In the second device, seeds were separated from pulverized seed head components with a Clipper™ Office Tester fitted with a 0.927 × 0.927 mm wire mesh top screen and a solid sheet bottom screen (A.T. Ferrell Company Inc., Bluffton, Indiana). The seed separator blower air ducts were open at 25% capacity and run until all material traveled past the screen sifters. Cleaned seeds were weighed to assess mass of seed recovered from each plant at each time interval.

Growing degree day equation

Cumulative GDD during each trial were calculated by using daily minimum and maximum temperatures (°C). Temperature measurements were recorded from the center of the experimental plots using a Hobo® Pro V2 logger (Onset®, Cape Cod, Massachusetts). GDD values were calculated as:

$$GDD_{daily} = \frac{T_{max} + T_{min}}{2} - T_{base}$$

Where

$$\Sigma GDD_{daily} = cumulative\ GDD$$

T_{max} and and T_{min} are maximum and minimum daily temperatures, respectively, and T_{base} is the base temperature where *P. torridum* growth and development is deemed not to occur (McMaster and Wilhelm, 1997; Lawson et al., 2006; Shrestha et al., 2010). In this study a T_{base} of 15 °C was utilized based on similar reported developmental parameters of native Hawaiian *H. contortus* grass, tropical *Panicum* grass species and tropical pasture grasses. (McWilliam, 1978; Baldos, 2013; Moreno et al., 2014).

Data analyses

Seed yield data were analyzed over both experimental trials using a split plot analysis of variance (Statistix 10.0; Analytical Software, Tallahassee, Florida), with experimental trial as the main effect and sample time as the split plot effect. A significant interaction was detected between the factors of experimental trial × sample interval, allowing for the seed yield means to be presented separately over trials. Based on significant F tests of seed yield over sample times, means were separated using Tukey's HSD test ($p \leq 0.05$).

Seed yield data were plotted against the cumulative GDD for each experimental trial to produce parametric equations and to determine the local maximum inflection point corresponding to maximum seed yield and GDD accumulation. The fit of the polynomial curves was based on the respective root mean square and adjusted R^2 values. Predictive equations and parameter estimates of the polynomial regression curves were plotted using JMP® Pro 11 (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Analysis results detected a significant interaction between the factors of experimental trial × sample interval on seed yield ($p < 0.001$), and thus were presented separately by trial. A significant effect of sample time on seed yield was also detected ($p < 0.001$). In the first experimental trial, maximum seed yield was found at the 4th sample interval (9 d after anthesis) amounting to 0.312 g of *P. torridum* seed for the three sampled heads, or an average yield of 0.104 g for one head (Table 1). In the second experimental trial, maximum seed yield was found at the 5th sample interval (12 d after anthesis) amounting to 0.319 g of seed over three heads, or an average yield of 0.106 g for one head. The maximum seed yield was not significantly different between the 4th sample interval in trial 1 and the 5th interval in trial 2. Seed yield maximums were recorded at differing sampling time intervals for plantings initiated in August and January. The shorter time to reach maximum mature seed yield

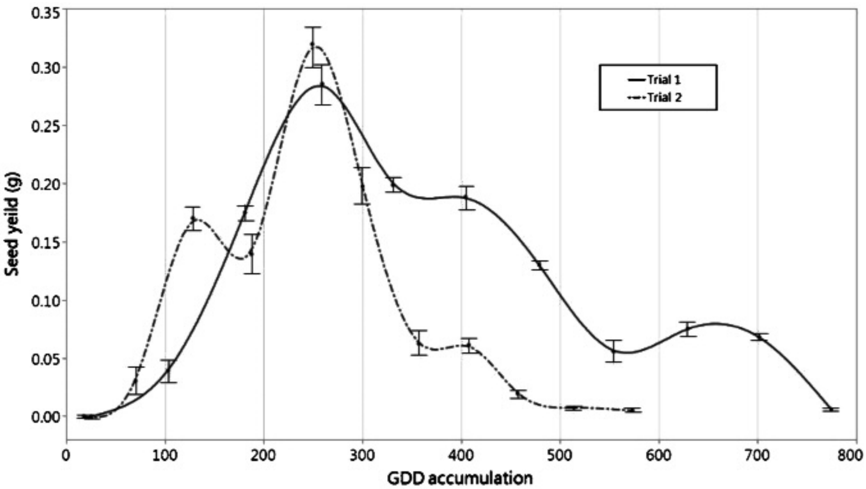
TABLE 1. *Panicum torridum* average seed yields from four experimental replications, over sample intervals from two experimental trials, 1 and 2, planted in August 2014 and January 2015, respectively.

	Seed yield†	
Sample interval	**Trial 1 (August)**	**Trial 2 (January)**
(d after anthesis)	(g)	
0	0.000 f‡	0.000 f
3	0.013 def	0.009 ef
6	0.048 c	0.055 bc
9	0.104 a	0.046 c
12	0.055 bc	0.106 a
15	0.055 bc	0.067 b
18	0.042 c	0.020 de
21	0.022 de	0.020 de
24	0.027 d	0.006 ef
27	0.026 d	0.002 f
30	0.002 f	0.002 f

† Analysis based on seed yields from three heads, but mean values are reported per individual seed head.

‡ Means within columns and rows, followed by the same letter, are not significantly different according to Tukey's HSD test ($p \leq 0.05$).

Figure 1. ***Panicum torridum*** **seed yield expressed over accumulated growing degree day (GDD) units, over two experimental trials. Maximum seed yield was obtained at 249 GDD in trial 1 (August 2014 planting) compared to 259 GDD in trial 2 (January 2015 planting).**



with the August planting was attributed to warmer temperatures than those associated with the January planting. This is expected as the intervals were based on chronological time of alternate seasons, August and January. Accumulated GDD units required for maximum seed yield followed a similar trend with fewer units required for the August planting (249) than the January planting (259). A total of 775 GDD units accumulated in the August planting cycle (i.e., anthesis to complete seed shatter) and 573 GDD accumulated in the January planting cycle (Fig. 1).

The least squares predictive equations for both experimental trials indicated that seed yield required a fifth degree polynomial expression. In the first trial, the predictive equation resulted in an R^2 value of 0.82 (Fig. 2):

$$\textit{Mature seed yield} = 0.5520302 - 0.0009395 * GDD - 9.5105e^{-7} * (GDD - 403.873)^2 + 1.9195e^{-8} * (GDD - 403.873)^3 - 2.34e^{-12} * (GDD - 403.873)^4 - 8.921e^{-14} * (GDD - 403.873)^5.$$

The second trial predictive equation resulted in an R^2 value of 0.83 (Fig. 2):

$$\textit{Mature seed yield} = 0.5626582 - 0.001232 * GDD - 5.5622e^{-6} * (GDD - 296.597)^2 + 3.8346e^{-8} * (GDD - 296.597)^3 + 3.956e^{-11} * (GDD - 296.597)^4 - 2.895e^{-13} * (GDD - 296.597)^5.$$

Results indicated that maximum mature seed yield for crops planted in August in Hawaii required 249 GDD after anthesis, and crops planted in January

Figure 2. Relationship between *Panicum torridum* seed yield and growing degree days (GDD), following two planting dates, August 2014 (trial 1) and January 2015 (trial 2). Regression analysis indicated that 5th degree polynomial curves best explained the relationship (see text for regression equations).

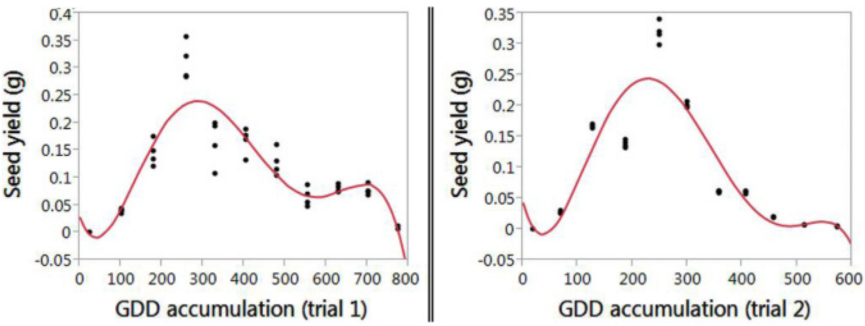
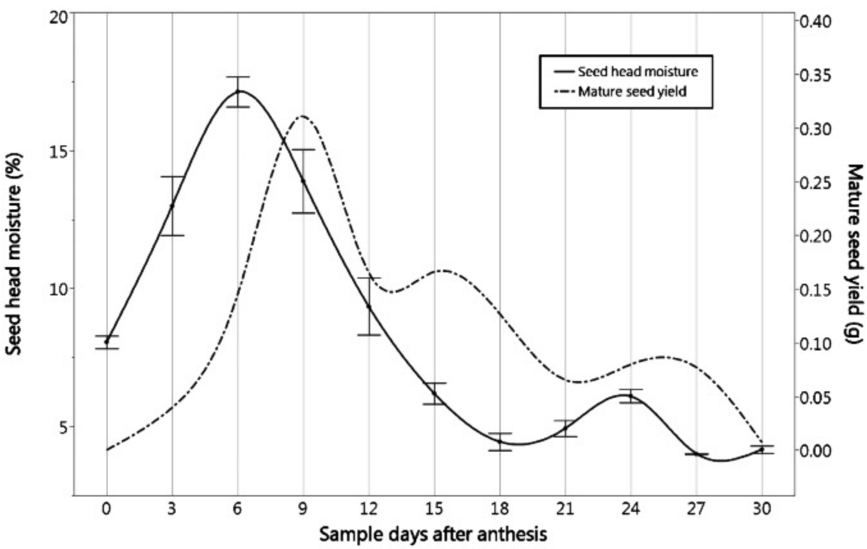
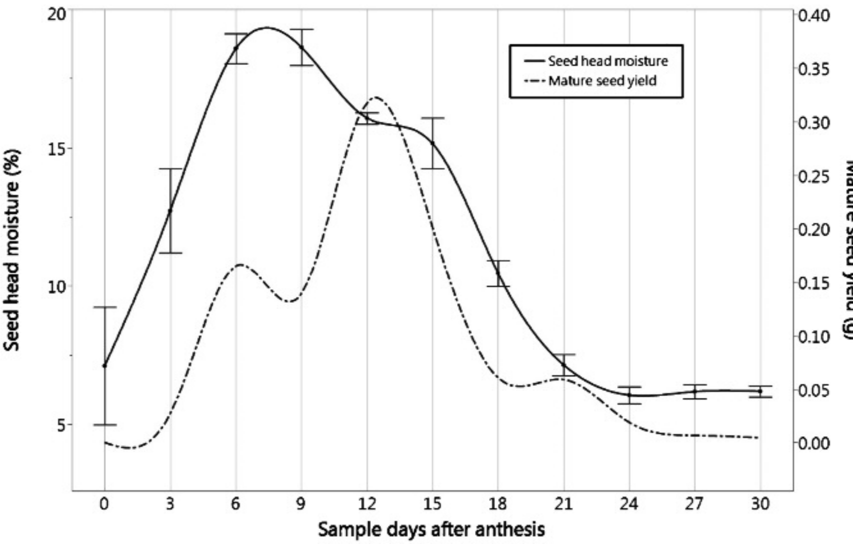


Figure 3. Changes in seed head moisture content and seed yield of *P. torridum* planted in August 2014 (trial 1), with chronological number of days after anthesis.



required 259 GDD. Seed head moisture content corresponding to maximum seed yield for the first trial was 18.6 % compared to the second trial of 16.1%. The general trend of seed head moisture content for both trials indicated that the highest moisture content was attained 3 d (one sample interval) before the peak harvest time, followed by a steady decline to full desiccation (Figs. 3 and 4). If the calculation of GDD is not available to predict maximum mature seed yield, the recommended harvest time to maximize seed yield in *P. torridum* is 9 chronological days post anthesis for August plantings and 12 d for a January planting.

FIGURE 4. Changes in seed head moisture content and seed yield of *P. torridum* planted in January 2015 (trial 2), with chronological number of days after anthesis.



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