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A Regional Assessment of Four Green Manure/Cover Crop Species Suited to Tropical Southeast Asia

Patrick J Trail (Corresponding Author)

ECHO Asia Impact Center, Thailand

Tim N Motis

ECHO, Inc., United States

Abram J Bicksler

ECHO Asia Impact Center, Thailand

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Abstract

While maintaining adequate levels of soil fertility can be a challenge on any farm, maintaining those levels on the resource-limited smallholder farms of the tropics requires options that are also affordable, practical, and appropriate in such challenging conditions. This research endeavor was designed to compare the adaptability and potential of four legume species promoted as Green Manure/Cover Crops (GMCC's) in Southeast Asia. Cowpea (*Vigna unguiculata*), Jackbean (*Canavalia ensiformis*), Lablab (*Lablab purpureus*), and Ricebean (*Vigna umbellata*) were planted in field trials in five diverse countries across Southeast Asia in 2016, including Cambodia, Myanmar, Thailand, Bangladesh, and the Philippines. Data was collected to assess the production of above-ground biomass, percentage of ground cover, and timing of growth cycles at each site. Although results varied from country to country based on soil-type, climatic conditions, and growing degree days, Jackbean consistently outperformed other GMCC species in terms of biomass production, yielding up to 12 t ha^{-1} on a dry-weight basis in Bangladesh and the Philippines. Of the four crops compared, cowpea consistently delivered the shortest growth cycle, reaching the pod formation stage in the fewest number of days across all five sites. These results provide informative answers regarding the growth habits and life cycles of these four crops across five diverse sites, and serve to enhance the capability of smallholders in Southeast Asia to select appropriate species needed for soil improvement purposes in a wide-ranging set of cropping systems.

Keywords: legumes, soil fertility, minimum tillage, ground cover, soil organic matter

1. Introduction

Beyond the initial increases in global crop production that typify the past decades, modern production practices have led to land degradation, rising debt, reduced biodiversity, and decreased soil fertility, thus exacerbating smallholder farmers' risk of chronic hunger. Leguminous green manure/cover crops (GMCCs) have gained increasing attention in recent years as a viable, low-cost means of restoring and sustaining the productive capacity of depleted soils. Through their unique ability to utilize nitrogen from the atmosphere, GMCCs can thrive on poor soils and supply large quantities of nutrient-rich biomass that builds organic reserves of soil fertility (Bunch, 1985; Fageria *et al.*, 2005; Sapkota *et al.*, 2012).

The use of Green Manure/Cover Crops (GMCC) for improving soil health and the long-term sustainability of crop production systems is not unfamiliar, and has been well documented by researchers and agriculturalists over time. Several researchers and numerous publications have sought to understand and give substance to the potential benefits of GMCC species and their ability for increasing soil organic matter (Guangwei *et al.*, 2006; Steenworth & Belina, 2008), reducing soil surface moisture losses (Russell, 1940), suppressing weeds (Liebl *et al.*, 1992; Teasdale *et al.*, 1991) reducing wind & water erosion (Alliaume *et al.*, 2014; De Baets *et al.*, 2011), moderating soil temperatures (Zibilske & Makus, 2009), fixing atmospheric Nitrogen (Tonitto & Drinkwater, 2006), breaking pest & disease cycles (Fageria *et al.*, 2005), and even bolstering soil biological life (Sapkota *et al.*, 2012).

However, with significant research having focused on the identification and testing of appropriate GMCC species in the temperate climates of the world, similar efforts are further needed for the testing of tropical climate counterparts. It is critical that further testing be aimed at smallholder production systems, specifically those found in the tropics and subtropics in order to bolster sustainable intensification and food security (Tilman *et al.*, 2011). Understanding the agronomic suitability of appropriate GMCC species across different regions, soil types, and climatic conditions will lead to better management decisions by local practitioners and producers. These management decisions, in turn, can lead to more sustainable systems and integrated agroecological approaches to help improve food security and environmental sustainability.

Cropping systems that can lead to any addition of soil organic matter can be crucial in smallholder settings where soil amendments are often scarce, expensive to purchase, or costly to apply. An effective GMCC species suited for the tropics can be especially beneficial in tropical soils where rainfall is high and soil organic matter is consumed by biological activity.

Adoption and familiarity of GMCC's remain localized within tropical Southeast Asia (Burnette, 2011), often by crop, location, and people group, but are being increasingly implemented and incorporated into various cropping systems (Burgers *et al.*, 2005; Sanchez, 1999). Further identification and research on individual GMCC species suitable for the region must complement existing work (Bunch, 1985; Fageria *et al.*, 2005). For instance, in China, Li *et al.* (2017) compared many legumes side by side, but the research was conducted from a grain production point of view rather than a strict soil building GMCC strategy.

This regional experiment was designed and implemented with the aforementioned objectives in mind, to study and assess four individual GMCC species side-by-side in field trials located within several countries across Southeast Asia, to better understand their suitability and

adaptability at each site. Species included Cowpea (*Vigna unguiculata*), Jackbean (*Canavalia ensiformis*), Lablab (*Lablab purpureus*), and Ricebean (*Vigna umbellata*) and were planted in field trials in Bangladesh, Cambodia, Myanmar, Philippines, and Thailand.

2. Materials & Methods

2.1 Experimental Design

Four different species of leguminous green manure/cover crops (GMCCs) were planted and evaluated during the 2016 rainy season in five different countries across Southeast Asia. Species included Cowpea (*Vigna unguiculata*), Jackbean (*Canavalia ensiformis*), Lablab (*Lablab purpureus*), and Ricebean (*Vigna umbellata*). Field trials were planted and replicated in Bangladesh, Cambodia, Myanmar, Philippines, and Thailand. Site conditions differed from one another in soil type and elevation, allowing for a more robust comparison of each species (Table 1).

Table 1. Site characteristics and planting dates at each of the five locations

Country	Elevation (m)	Soil Texture	Soil pH	Organic Matter (%)	Planting Date (2016)
Bangladesh	25	Loam	5.85	2.89	14 August
Cambodia	500	Clay (red)	4.5	6.14	27 August
Myanmar	1376	Silt Loam	5.82	1.36	01 August
Philippines	55	Clay	-	-	09 October
Thailand	310	Sandy Loam	6.5	2.56	10 August

All sites were planted in August, 2016, towards the end of the rainy season, except for the Philippines site which had a delayed planting into the month of October. In an effort to ameliorate some of these differences in growing conditions across sites, we calculated Growing Degree Days (GDD) at each site, using the following formula (Figure 2):

Growing Degree Days = ((Maximum Temperature – Minimum Temperature) / 2) – Minimum Temperature for Crop Growth

For the purposes of this study we selected 10^{o}C as the minimum temperature for crop growth, which is the temperature often utilized when calculating GDD for maize (McMaster & Wilhelm, 1997).

Individual field trials within country were designed with a Randomized Complete Block Design (RCBD) in mind, replicated 4 times, with individual plots of 2m x 2m in area. All GMCC's were planted in a 50cm x 50cm planting arrangement with 2m alleys between plots. Three seeds were planted per hill and thinned to one plant within 2 weeks of planting. E Half of each plot was used for destructive sampling purposes, while the other half was left untouched for overall biomass calculation and time to pod formation (in days). Sampling of GMCCs took place at 50% flowering in each plot, whereby above-ground biomass was collected by half plot to determine the dry weight of above-ground biomass produced. A 200g sample of fresh biomass was oven-dried to constant weight for each of the different species and was used to calculate dry matter of the different species.

Days from planting to 50% flowering were also recorded to assess duration of individual species. Days from planting at 50% flowering was used to best calculate biomass production at the plant's stage of peak vegetative growth. Above-ground and below-ground soil data loggers were also buried at each site to measure soil temperature over the course of the growing season; Onset HOBO Pendant Temperature data loggers were used in this experiment (Onset Computer Corporation, Bourne, MA).

2.2 Plot Management

In an effort to assess the overall adaptability and potential of each of the GMCC species within each of the sites, the management of field plots was left to a minimum. No soil amendments were applied and crop pest protection was withheld. Plots were weeded once every two weeks until GMCCs became adequately established and began to suppress weeds on their own.

2.3 Statistical Analysis

Pearson's Correlation tests were run between above ground dry biomass production and days to harvest of legume species with the climate-influenced factors of rainfall, temperature, and Growing Degree Days using SAS (SAS Institute Inc., Carey, NC). Data collected at each site were submitted by collaborators using the online data collection and analysis software Liquid Data Management (Liquid Data Management, location, USA).

3. Results

3.1 Rainfall & Temperature

Although each of the sites were located within the tropics and within the same Southeast Asia region, rainfall totals, frequency of rainfall, soil temperatures, and air temperatures all varied across the sites (Figure 1; Table 1). Total rainfall during the growing period of the field trials ranged from as little as 908 mm in the Philippines to as high as 2125 mm in Bangladesh (Table 1).

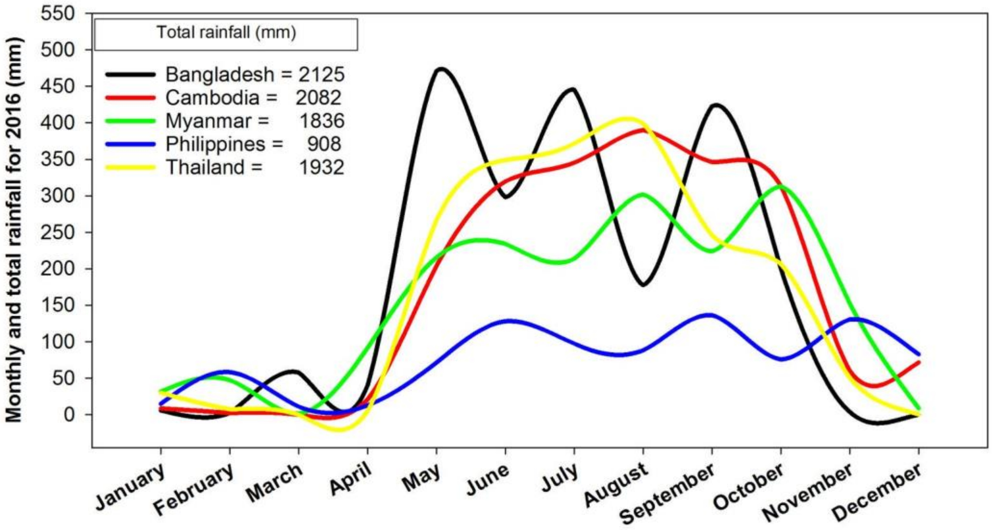

Figure 1. Monthly rainfall data, and cumulative rainfall (mm) at each of the study locations

Since mean daily temperatures fluctuated considerably, the calculation of Growing Degree Days was used as a means of ameliorating site climatic differences (Figure 2). Myanmar, having the highest elevation of the sites, at 1376 m, experienced the coolest temperatures and subsequently the lowest number of cumulative Growing Degree Days, while Bangladesh, with the lowest elevation, at only 25 m above sea level, experienced much higher temperatures and had the overall highest number of cumulative Growing Degree Days.

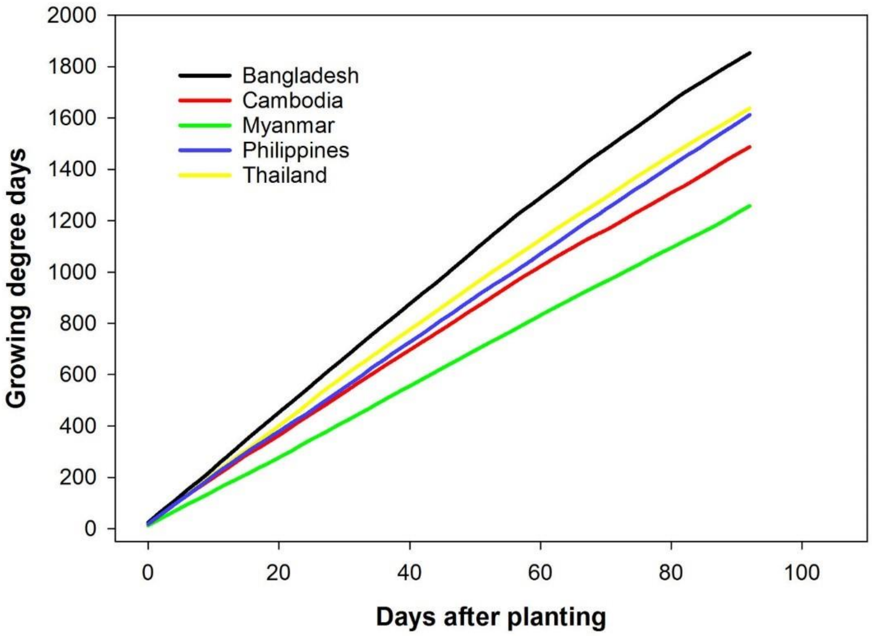

Figure 2. Growing Degree Days (GDDs) accumulated by DAP (Days After Planting) across each of the five sites

3.2 Days to Harvest

Overall, cowpea matured the fastest of any of the legumes. Cowpea matured fastest (45 days after planting on average) at the Bangladesh site, a finding consistent with the fact that GDD accumulated the fastest in Bangladesh (Figure 2). Statistically, cowpea harvest time was strongly and inversely correlated (Pearson correlation coefficient [PCC] > -0.93; P <0.0001) with GDDs, suggesting that cowpea maturation time decreased with increasing GDDs. Jackbean, Lablab, and Ricebean took about three months to begin producing pods (Figure 3). Providing late-season ground coverage and food/fodder options for humans and/or livestock, longer-term legumes (such as Jackbean, Lablab, and Ricebean) are good options for increasing dry-season productivity, as long as the preceding rainy season is long enough for them to become established.

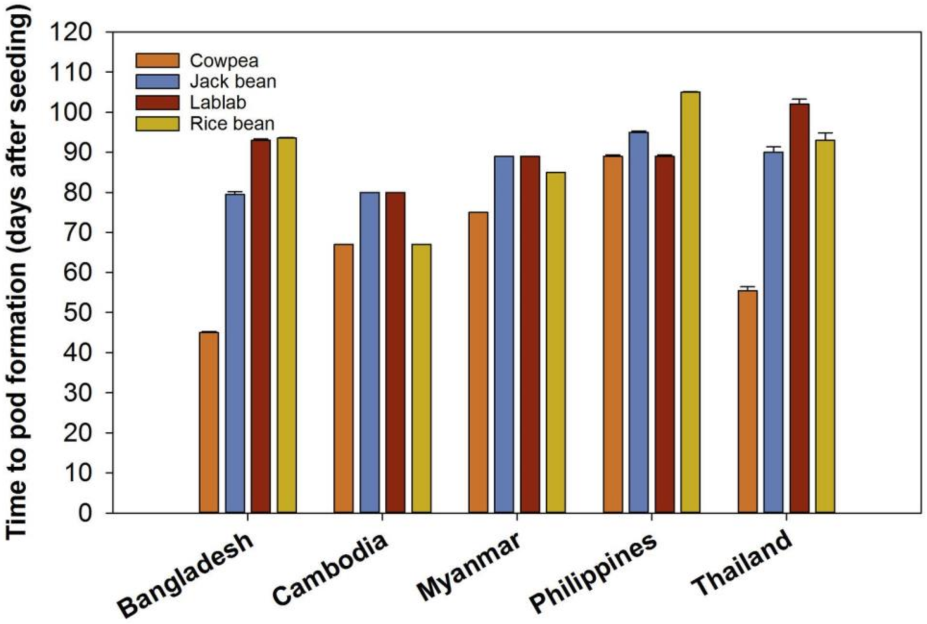

Figure 3. Time to pod formation (Days After Seeding) for each legume species at each of the five sites

3.3 Biomass Production

Jackbean produced the most aboveground dry biomass in each of the locations, generating the equivalent of 12 t ha^{-1} of dry matter in Bangladesh and the Philippines and 9 t ha^{-1} in Thailand. Ricebean generated close to 9 t ha^{-1} in Bangladesh and 6 t ha^{-1} in Thailand. Cowpea produced 5 or more t ha^{-1} in the Bangladesh and the Philippines.

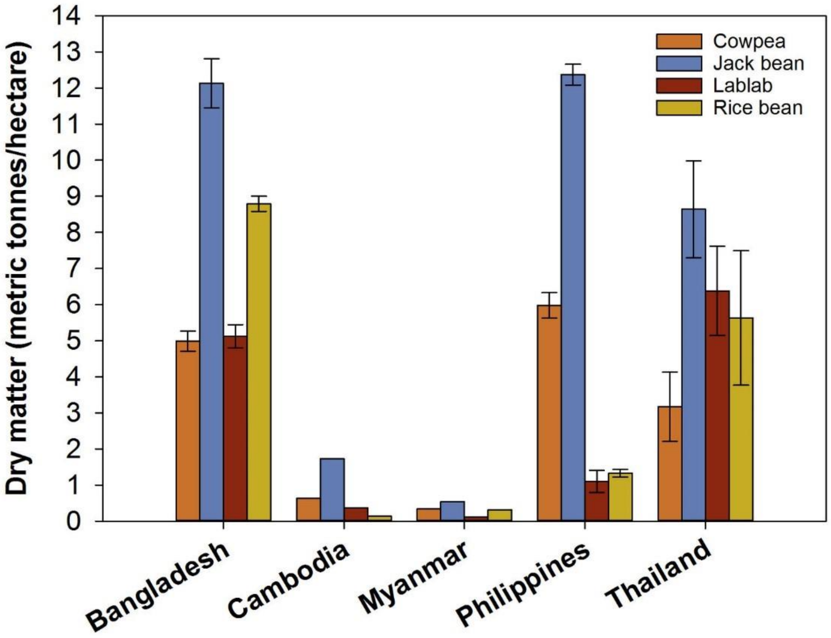

Figure 4. Aboveground dry biomass production (t ha^{-1}) for each legume species at each of the five sites

In general, the legumes were much better correlated with soil than air temperatures. In this trial, soil temperature was measured on site, whereas air temperature was measured some distance away from the soil. Nevertheless, soil temperature reflects conditions experienced by plant roots, which could be significant in determining plant growth characteristics. Overall, legume dry matter correlated more closely with early- (months 1 and 2) than later- (month 3) season temperatures (Appendix 1). An exception was Lablab dry matter, which correlated best with month-3 minimum soil temperatures and maximum air temperatures. Rainfall appeared to be a more important factor for Lablab and Ricebean than Cowpea and Jackbean, in terms of biomass production. For Lablab, dry biomass was correlated with early rainfall (month 1) but not later rainfall (months 2 and 3) in the growing season, suggesting the importance of rainfall for early-season establishment of GMCCs.

GDDs were strongly correlated with dry biomass produced by each legume. Using a minimum base temperature of 10^{o}C (same number used for maize GDD calculations) appears to be a good way to calculate GDD for the legumes trialed.

4. Discussion

With its tendency to establish quickly, Cowpea could be a good choice of a Green Manure Cover Crop for areas with short rainy seasons that accumulate heat units (GDDs) quickly. The establishment of early-season ground coverage is another reason to select a fast-growing legume, which can also begin suppressing weeds and reducing soil evaporation much sooner in the growing season.

None of the legumes grew well at the Cambodia and Myanmar sites. Some key insights, however, can be learned from these sites about factors that limit legume growth. Two factors that appear to be important here are soil phosphorus content and cool temperatures. Maejo University in Thailand tested the soil from the Cambodia site and categorized its phosphorus level as “very low” (only 2 ppm; 10 to 12 ppm would have been needed for “moderate” status). By comparison, the soil in Bangladesh had 438 ppm phosphorus. As noted in previous work, phosphorus availability is often correlated with low pH soil, which could be the greater underlying issue in the Cambodia site **(**Fageria *et al.*, 2009). Legumes also need phosphorus to be able to fix nitrogen, which could further exacerbate the problem. It is also possible that root growth could have been restricted by the clay soil. The Myanmar site received enough rainfall (Figure 1) and had a more ideal soil, being a silt loam. At 1,376 m in elevation, though, minimum temperatures in Myanmar were on the cool side (Figure 1).

Overall, legumes grew the best in Bangladesh and in Thailand (Figure 4). Both of these sites had a medium (loamy) soil texture, rapidly accumulated GDDs, and received high amounts of rainfall. Although cowpea and jack bean thrived at the Philippines site, lablab and rice bean did not. The Philippines site was the driest of the five sites (Table 1), so perhaps there was not enough rainfall for lablab and rice bean to become established. Although Lablab is known for its deep roots and drought resistance, it would appear that it needs more moisture during a slow establishment phase.

Legumes grown as GMCCs can be a valuable option for maintaining soil health. Success, however, depends on matching legumes to local growing conditions and farmer needs and constraints (Bunch, 1985). There are numerous tropical legume species to choose from. Learning about the local context is key to deciding what legumes could potentially grow well in a given area. Factors such as climate requirements, soil preferences, and growth habit are also important. It is also important to note that not 100% of the GMCC-derived nutrients will remain in the field as the byproduct of growing the GMCC, as in many realistic smallholder farm settings, a certain portion of the crop will be harvested and leave the field. While the biomass of a GMCC may remain in the field, often times the pods or the grain will be harvested for human or livestock consumption, and while it is not recommended, a portion may even be removed for fodder.

5. Conclusions

Based on this body of work, we can recommend that growers seeking to produce higher amounts of biomass (over 10 t ha^{-1}) over a longer period of time (45 days or more) should consider planting Jackbean, while those with a shorter window (less than 45 days) might consider planting cowpea. Cowpea, Lablab, and Ricebean all produced sufficient amounts of biomass to cover the soil and supply sufficient organic matter, but never reached the 12 t ha^{-1} level as that of Jackbean. In the end, the species selected for use as a GMCC must fit the needs of the grower, the cropping system, and the climatic conditions.

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Glossary

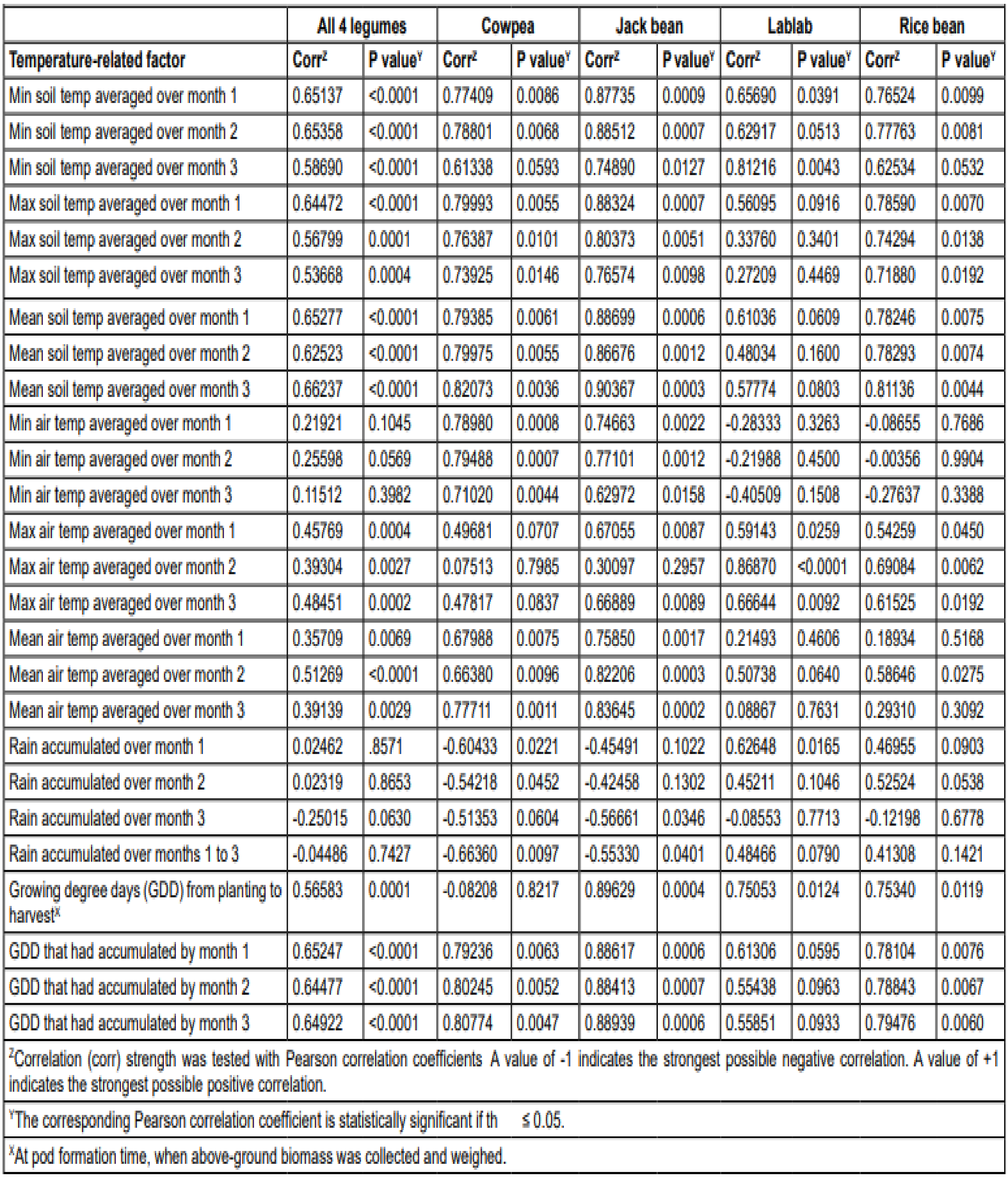
GDD: Growing Degree Days

GMCC: Green Manure/Cover Crop

RCBD: Randomized Complete Block Design

Appendix

Strength of correlation between legume biomass (of all species) and temperature related factors using Pearson Correlation Coefficient in SAS.



	All 4 legumes		Cowpea		Jack bean		Lablab		Rice bean	
Temperature-related factor	Corr^Z	P value^Y	Corr^Z	P value^Y	Corr^Z	P value^Y	Corr^Z	P value^Y	Corr^Z	P value^Y
Min soil temp averaged over month 1	0.65137	<0.0001	0.77409	0.0086	0.87735	0.0009	0.65690	0.0391	0.76524	0.0099
Min soil temp averaged over month 2	0.65358	<0.0001	0.78801	0.0068	0.88512	0.0007	0.62917	0.0513	0.77763	0.0081
Min soil temp averaged over month 3	0.58690	<0.0001	0.61338	0.0593	0.74890	0.0127	0.81216	0.0043	0.62534	0.0532
Max soil temp averaged over month 1	0.64472	<0.0001	0.79993	0.0055	0.88324	0.0007	0.56095	0.0916	0.78590	0.0070
Max soil temp averaged over month 2	0.56799	0.0001	0.76387	0.0101	0.80373	0.0051	0.33760	0.3401	0.74294	0.0138
Max soil temp averaged over month 3	0.53668	0.0004	0.73925	0.0146	0.76574	0.0098	0.27209	0.4469	0.71880	0.0192
Mean soil temp averaged over month 1	0.65277	<0.0001	0.79385	0.0061	0.88699	0.0006	0.61036	0.0609	0.78246	0.0075
Mean soil temp averaged over month 2	0.62523	<0.0001	0.79975	0.0055	0.86676	0.0012	0.48034	0.1600	0.78293	0.0074
Mean soil temp averaged over month 3	0.66237	<0.0001	0.82073	0.0036	0.90367	0.0003	0.57774	0.0803	0.81136	0.0044
Min air temp averaged over month 1	0.21921	0.1045	0.78980	0.0008	0.74663	0.0022	-0.28333	0.3263	-0.08655	0.7686
Min air temp averaged over month 2	0.25598	0.0569	0.79488	0.0007	0.77101	0.0012	-0.21988	0.4500	-0.00356	0.9904
Min air temp averaged over month 3	0.11512	0.3982	0.71020	0.0044	0.62972	0.0158	-0.40509	0.1508	-0.27637	0.3388
Max air temp averaged over month 1	0.45769	0.0004	0.49681	0.0707	0.67055	0.0087	0.59143	0.0259	0.54259	0.0450
Max air temp averaged over month 2	0.39304	0.0027	0.07513	0.7985	0.30097	0.2957	0.86870	<0.0001	0.69084	0.0062
Max air temp averaged over month 3	0.48451	0.0002	0.47817	0.0837	0.66889	0.0089	0.66644	0.0092	0.61525	0.0192
Mean air temp averaged over month 1	0.35709	0.0069	0.67988	0.0075	0.75850	0.0017	0.21493	0.4606	0.18934	0.5168
Mean air temp averaged over month 2	0.51269	<0.0001	0.66380	0.0096	0.82206	0.0003	0.50738	0.0640	0.58646	0.0275
Mean air temp averaged over month 3	0.39139	0.0029	0.77711	0.0011	0.83645	0.0002	0.08867	0.7631	0.29310	0.3092
Rain accumulated over month 1	0.02462	.8571	-0.60433	0.0221	-0.45491	0.1022	0.62648	0.0165	0.46955	0.0903
Rain accumulated over month 2	0.02319	0.8653	-0.54218	0.0452	-0.42458	0.1302	0.45211	0.1046	0.52524	0.0538
Rain accumulated over month 3	-0.25015	0.0630	-0.51353	0.0604	-0.56661	0.0346	-0.08553	0.7713	-0.12198	0.6778
Rain accumulated over months 1 to 3	-0.04486	0.7427	-0.66360	0.0097	-0.55330	0.0401	0.48466	0.0790	0.41308	0.1421
Growing degree days (GDD) from planting to harvest^X	0.56583	0.0001	-0.08208	0.8217	0.89629	0.0004	0.75053	0.0124	0.75340	0.0119
GDD that had accumulated by month 1	0.65247	<0.0001	0.79236	0.0063	0.88617	0.0006	0.61306	0.0595	0.78104	0.0076
GDD that had accumulated by month 2	0.64477	<0.0001	0.80245	0.0052	0.88413	0.0007	0.55438	0.0963	0.78843	0.0067
GDD that had accumulated by month 3	0.64922	<0.0001	0.80774	0.0047	0.88939	0.0006	0.55851	0.0933	0.79476	0.0060

^{Z}Correlation (corr) strength was tested with Pearson correlation coefficients A value of -1 indicates the strongest possible negative correlation. A value of +1 indicates the strongest possible positive correlation.

^{Y}The corresponding Pearson correlation coefficient is statistically significant if th ≤ 0.05.

^{X}At pod formation time, when above-ground biomass was collected and weighed.

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