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Agronomic Potential of Lupin (*Lupinus* spp.) in Sri Lanka as an Alternative Crop: Growth and Yield Performance in Different Agro-ecological Regions

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ABSTRACT
Lupin (*Lupinus* spp.), a pulse crop gained popularity throughout world as a protein-rich-healthy human and animal food. *Lupinus luteus* (yellow-Lupin), *Lupinus albus* (white-Lupin) and *Lupinus angustifolius* (narrow-leafed-sweet-Lupin) varieties are commercially cultivated. Lupins are cultivated in many countries. Diverse climatic conditions with fertile soil provide a high possibility to introduce commercially-developed lupin varieties to Sri Lanka. With the primary objective of exploring possibilities of cultivating lupins in Sri Lanka and to select appropriate varieties and suitable Agro-Ecological Regions (AERs), a field experiment was conducted with ten commercially cultivated *Lupinus* varieties, *L. albus* (var. Kiev mutant), *L. luteus* (var. Wodjil, Pootalong), *L. angustifolius* (var. Ganguru, Tanjil, Walan, Belara, Donja, Kalya, Mandelup). Agro-morphological characters, time to flowering, number of seeds/plant, whole plant biomass were measured to assess growth and yield performance in AERs, Matale, Bandarawella and Nuwara Eliya for two consecutive years. Randomized complete block design was used with four replicates. Lupin varieties developed well in Nuwara Eliya and Bandarawella. Growth and yield performance of *L. albus*, *L. luteus* and *L. angustifolius* varied across AERs. Seedlings of lupin were better acclimatized to AERs, Nuwara Eliya and Bandarawella. Variation of temperatures in the range of 16 and 200°C was a crucial requirement for successful flowering and pod setting. Soil nutrients, soil organic matter as well as variation of soil pH were important factors for successful growth of lupins. Further field studies are recommended for a better understanding the impact of eco-climatic conditions on growth and yield performance of lupins in Sri Lanka.

Key words: Agro-ecological regions, Lupin, *Lupinus* spp. Sri Lanka

INTRODUCTION
The climate of Sri Lanka is broadly classified as tropical with wide variation in rainfall, temperature and relative humidity and varying soil types in wet, dry, intermediate and central highlands (Domros, 1974; Panabokke, 1996). Thus, Sri Lanka is a country having diverse agro-climatic conditions with fertile soil in many areas and there is a higher potential of diversification of agriculture depending on the need of the country varying from time to time. However, adaptive measures need to be implemented for future food security and safety. Under the Open Economic Concept, less attention has been paid to local agriculture and greater extents of

arable lands in the country became underutilized. Meanwhile, a considerable amount of foreign exchange is spent on the import of food items including many protein rich pulses such as soy, lentils, green gram, chick pea, cowpea etc., amounting to an increase of 22, 320 Mt in 1985-97, 170 Mt in 2005 (FAO, 2008). The trade deficit of export and import of the country for the year 2007 was US$ 3626.5 million (Ministry of Finance and Planning, 2008). Though it is not yet a national level issue, a majority of the population in country is falling under low-income group due to lack of carrier skills to obtain employments. The average monthly house hold income by poverty status of poor-urban, poor-rural, poor-Estate, non-poor-urban, non-poor-rural and non-poor-Estate were Rs. 12,513/=, 11,594/=, 10,640/=, 43,476/=, 25,913/= and 22,297/=, respectively (Department of Census and Statistics 2010). This situation leads to poor buying power, especially for the food commodities. The malnutrition is an obvious manifestation of such communities at least among the young children, pregnant mothers and the low-income group (FAO, 1992). Therefore, as a remedial measure raising agricultural production of pulse crops obviously would have a positive impact on under- and malnutrition (Anonymous, 2007).

Introduction of commercially developed lupin varieties as an alternative crop to Sri Lanka will fulfill the demand of protein rich food for human and livestock feed and as a fodder and green manure. Meanwhile, lupins increase the yield of the crops which are on rotation by fixing atmospheric nitrogen (Herridge and Doyle, 1988) and organic matter to soil (Wieland *et al*., 1997).

The genus *Lupinus* belongs to the family Fabaceae (Sub-family: Papilionoideae) includes more than 200 species distributed in the Eastern (Mediterranean-African) and Western (American) Hemispheres (Cowling *et al*., 1998). There are 12 species of lupin in the Mediterranean region and Africa (Gladstones, 1998). Among the species there are 11 annual species and one perennial which is possibly been disappeared. Lupin grows in this region on light-textured soils, mainly at small heights or on seacoasts. Most of the species are characterized by one-year-long or frequently winter mode of life and have large seeds. This is also typical for other plants of this centre of distribution. Some of the rather small quantity of species in Mediterranean region are domesticated and widely cultivated in Australia and in many countries of Europe, Asia and Africa. Among the most widely introduced lupin species in many countries, *Lupinus albus* L. (white lupin), *Lupinus angustifolius* L. (narrow-leafed sweet lupin) and *Lupinus luteus* L. (yellow lupin). *Lupinus cosentinii* Guss, L. *atlaticus* Gladstones and *Lupinus pilosus* Murr., were domesticated in Australia quite recently and are now cultivated (Cowling *et al*., 1998).

At present, lupins (white, narrow-leafed-sweet and yellow lupins) are cultivated in many countries all over the world. The largest producers of lupines in the world include Australia (143 Million t/a), South America (54,450 t/a), France (24,000 t/a), Italy (5,000 t/a) and Spain (9,800 t/a) and used for feed and food applications. In addition to these major lupin producers, Egypt, Sudan, Ethiopia, Syria, USA, Tropical and Southern Africa, Russia and Ukraine also cultivate lupin in substantial amounts (FAOSTAT, 2008). Lupin is Australia's largest pulse (grain legume) crop and Australia is the largest exporter of lupins in the world (French and Buirchell, 2005). A number of lupin varieties have been developed in Australia, to suit for a wide range of soil types, soil pH, rainfall and resistance to diseases and pests (GRDC, 2006) and commercially cultivated narrow-leafed sweet lupin varieties include Mandelup, Tanjil, Wonga, Ganguru, Belara, Walan and Jindalee. These varieties have varying flowering dates, maturities and ability to pod under lush vegetative conditions. They also have varying levels of resistance and susceptibility to diseases. Kiev mutant, Luxon and Rosetta are the commercially cultivating white lupins. Among yellow lupins, Woodjil, Pootalong and Ukraine are the most popular varieties (GRDC, 2006).

Australia represents a varying of climatic conditions wide range from tropical, sub-tropical, Mediterranean, semi-arid, temperate, to cold. Western Australia has a Mediterranean climate (Palta *et al*., 2004) and lupins are starting to grow from May to September in which climate is wet and temperature is gradually changing from mild to cold.

Wild lupins contain significant amounts of secondary compounds like isoflavones and alkaloids which give a bitter taste and these alkaloids possess a higher teratogenic potential (Keeler, 1976). The alkaloids that contribute to the bitter taste of lupin kernels in modern varieties have been reduced to very low levels through conventional breeding techniques such as mutagenesis (Duranti and Gius, 1997). These mutant types contained only 0.05% alkaloids and are palatable, safe to eat and have non-shattering pods and soft seeds (Gladstones, 1998). Lupins are widely used as a source of protein and energy in livestock feeds. Their high protein content makes them a valuable resource for monogastric and ruminant production systems. Both sweet lupins and white lupin varieties in their whole-seed and kernel meal forms are using to feed fish and prawns as a substitute for a protein resource (Dixon and Hosking, 1992). The sweet lupin flour consists of high protein levels of 30-40%, high dietary fiber (30%) and low fat and has a very low glycaemic index. Most of the essential amino acids such as lysine (1.46 g/100 g), isoleucine (1.22 g/100 g), glycine (1.29 g/100 g), histidine (0.79 g/100 g) and serine (1.59 g/100 g) are present in high contents in sweet lupin and is of importance in human nutrition (Champ, 2001). In addition, an interesting feature of lupin is the very low (or nil) content of anti-nutritional factors, such as phytate, tannins, lectins, protease inhibitors and indigestible oligosaccharides (Muzquiz *et al*., 1998). In contrast to other leguminous plants (peas, soy, beans) lupins contain extremely low amounts of trypsin inhibitors, lectins, isoflavones, saponins and cyanogens.

Lupin seeds deliver a number of health benefits to counter "Metabolic Syndrome"; a collection of health problems associated with obesity, high blood pressure, insulin resistance and elevated cholesterol. Thus, foods containing lupins can suppress appetite, benefit glycaemic control, improve blood lipids and bowel health and reduce hypertension (Drake, 2008; Sipsas, 2008). In contrast to other leguminous plants (peas, soy beans, beans) lupins contain extremely low amounts of trypsin inhibitors, lectins, isoflavones, saponins and cyanogens (Hall *et al*., 2005). Lupins and lupin products have traditionally formed part of the human diet. The requirements with regard to chemical composition, nutritional values and product safety were laid down by the Advisory Committee on Novel Foods and Processes (ACNFP) in 1996 for certified lupins (sweet lupins) and on the strength of that these products were recommended as foodstuffs and food ingredients e.g., Lupin flours for baked goods (Hall *et al*., 2005). Food products available on the market are lupin snacks, lupin pasta, lupin bread and cookies, lupin coffee and some vegetarian instant meals (DAFWA, 2006). Lupin sprouts are used as a salad vegetable, in stir-fries or for pickling. Lupin seeds are used in traditional Indonesian and Japanese food. Green immature seeds are used as an alternative for green peas (DAFWA, 2006).

Lupins are one of the easier and lower cost pulse crops to grow. They are well adapted to areas with above 350 mm rainfall. They suit most soils provided they have low free lime (carbonate) levels and do not water log for extended periods. Lupins tolerate acidic soils down to pH 4.0. Suitable soil types include sand, deep sandy loam, sand over clay and well-structured loams. Temperature above 20°C at flowering can cause flower abortion (GRDC, 2008). Lupins can be grown as a rotational crop with cereals or vegetable crops. Cereal and crop yields are higher after Lupin as they fix nitrogen and improve soil conditions (GRDC, 2006). Normal plant growth processes occur in a wider range of temperatures, approximately 0-35°C. The biological processes such as germination, leaf growth and plant development (for example, time to flowering) are depending on the temperature. Lupins are not susceptible to most phytopathogenic bacteria and fungi. *Rhizoctonia* root rot and *Phytopthora* root rot are exceptions and treating seeds with a fungicide prior to sowing is one of the best practices in controlling or preventing these infections (Thomas *et al.*, 2008).

With the primary objectives of exploring the possibility of cultivating lupins in Sri Lanka and to select appropriate varieties and suitable Agro-Ecological Regions (AER), an experiment was conducted using ten commercially cultivated *Lupinus* genotypes comprising of *L. albus* (white lupin), *L. luteus* (yellow lupin) and *L. angustifolius* (narrow-leafed, sweet lupin) varieties.

MATERIALS AND METHODS

Area of study: Considering the diverse climatic conditions and soil types in Sri Lanka, three (03) Agro Ecological Religions (AERs) were selected (Fig. 1) for field experiments. A pot experiment was conducted in Matale (IM_3), Nuwara Eliya (WM_3) and Bandarawela (IU_3) in 2008 to study the yield and biomass performance of different varieties of lupins prior to field experiment (Weerakoon and Somaratne, 2010). In the present experiment, field trials were carried out in the same agro-ecological regions for two consecutive years, 2009 and 2010, where pot experiments were conducted.

Materials: Ten commercially cultivated *Lupinus* genotypes i.e., seven *L. angustifolous* (narrow-leafed, sweet lupin) varieties (Ganguru, Tanjil, Walan, Belara, Danja, Kalya, Mandelup), two *L. luteus* (yellow lupin) varieties (Woodjil, Pootalong) and one *L. albus* (white lupin) variety (Kiev mutant) were obtained from the Department of Agriculture and Food Western Australia(DAFWA, 2006), Australia.

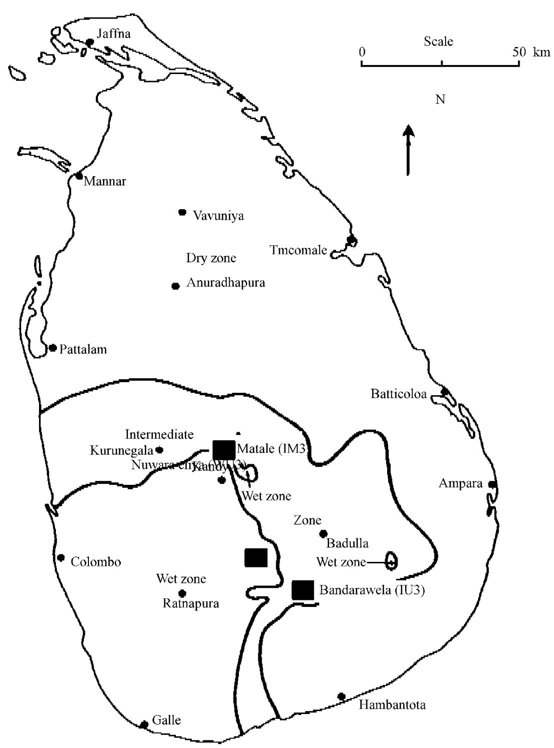

Fig. 1: Selected sites for the field experiment for different lupin varieties in Sri Lanka

The experimental design used in the field trial was Randomized Complete Block Design (RCBD) with four replicates. The plot sizes of the experiment were 1.5 by 5.2 m for the year 2009 and 1.5 by 5.8 m for the year 2010 for each site selected for the experiment. The plots were sown on 17th October, 2009 and 20th October, 2010 during the onset of the North East Monsoonal period. The Osmocote®, a controlled releases fertilizer (nitrogen, phosphate and potassium and trace elements-Scotts Australia Pty Ltd., Bella Vista, NSW 2153 and Australia) was applied before sowing seeds at a rate of 112 kg ha^{-1}. In both years, ground was tilled up to 12 cm depth and seeds were sown in rows with a density of 30 seed m^{-2} and distance between the rows was 18 cm.

In both years, five (05) soil samples were taken to 15 cm depth at random from each plot located in each AER. These soil samples were air dried and were subjected to analysis for the same soil parameters of different study sites were obtained. One half of the each plot was used to biomass sampling and the other half for seed sampling. Biomass samples were taken at about 50% onset of flowering. Seed samples were taken at maturity of the crop. In both cases the samples were taken from the middle two rows excluding the boarder rows. The fresh weights of the fresh biomass samples were measured to estimate green biomass. The biomass samples were dried in an oven at 65°C to a constant weight for dry matter determination. The collected seed samples air dried at room temperature to a constant weight before determination of seed weight.

Soil pH was measured immediate after the sampling. Duplicate 20 g field moist sub-samples from the bulked soil sample using the supernatant of 1:2:5 soil suspensions in deionized water and measurement was made using pH meter with glass calomel electrode (Anderson and Ingram, 1993). The organic matter in the soil samples were determined by wet oxidation method (Nelson and Sommers, 1982; Anderson and Ingram, 1993). The total nitrogen contents of the soil samples were determined using an Autoanalyzer (Tecator 1030 Kjeltec Autoanalyzer, Foss Tecator AB, Box 70, S-263 21 Höganäs, Sweden).

The soil K was extracted using Modified Morgan extractant (McIntosh, 1969). Measurements of cations K in soil extract were performed in standardized atomic absorption spectrometer (GBC 932AA, GBC Scientific Instrument, 12, Monterey Road, Dadenong, Victoria 3175, Australia). The extractable soil P was determined according to the method described by Watanabe and Olsen (1965). The total nitrogen and total phosphorous contents of the soil samples were determined according to Anderson and Ingram (1993).

The readings for number of seeds/plant (estimated as Seed yield, kg ha^{-1}), biomass production at maturity (PLBIO) and time taken to onset flowering (FT) were taken. Mean annual precipitation and mean annual temperature of ten year's data for the selected sites were obtained from the Meteorological Department, Colombo, Sri Lanka. Elevation, soil type, mean monthly temperature, rainfall and great soil group are given in Table 1 and 2. Some selected soil properties; pH, soil organic matter content, P, K and N percentage and C:N ratio were analyzed for the study sites (0-30 cm) in 2009 and 2010.

Table 1: Agro ecological zone, elevation and soil type of the areas chosen for the study

Site/agro ecological regions (AER)	Elevation (m)	Soil (Soil Survey Staff, 2003)
Matale-IM_3	1160	Rhodudults and Tropudults
Nuwara Eliya-WU_3	1800	Rhodudults and Kandiudults
Bandarawela-IU_3	1230	Rhodudults and Kandiudults

Table 2: Mean monthly rainfall (mm) and temperatures (°C) from ten years data for the locations chosen for the study (Anonymous, 2008)

Location	October	November	December	January
Temperature (°C)				
Bandarawela (IU_3)	23.54±0.04	22.66±0.06	21.71±0.07	21.16±0.06
Matale (IM_3)	25.43±0.05	25.23±0.04	24.74±0.05	24.62±0.07
Nuwara Eliya (WU_3)	15.47±0.05	15.27±0.06	14.67±0.06	14.24±0.07
Rainfall (mm)				
Bandarawela (IU_3)	232.94±12.03	270.45±11.45	299.07±16.26	217.12±17.03
Matale (IM_3)	286.97±10.58	274.85±10.29	218.37±12.63	121.55±10.38
Nuwara Eliya (WU_3)	258.02±10.34	222.38±8.280	205.89±12.74	136.91±11.08

Values are as Mean±SD

Statistical analyses: Statistical analyses were made using the Proc GLM module of the SAS Version 9.2 (SAS Inc., 2008). A preliminary analysis of variance carried out for the combined data set, site, year and cultivars as fixed effect in a factorial model. Subsequently, analysis of variance performed on the individual sited for each year using a randomized complete block design. Mean separations were carried out using Tukey's hsd test.

RESULTS

The Maha season (1st October to 31st December) rainfall at Bandarawela site was 254 and 225 mm at Matale site. The average rainfall during Maha season at Nuwara Eliya was 205 mm. Average temperature at Bandarawela site was 22 and 24°C at Matale. Nuwara Eliya site showed the lowest average temperature of 15°C (Table 2).

The soil properties and soil nutrient contents in the three selected locations for 2009 and 2010 vary considerably across the sites (Table 3). Soil pH of the site at Matale (IM_3) was significantly different from pH values of the sites at Bandarawela (IU_3) and at Nuwara Eliya (WU_3) in both 2009 and 2010. Soil organic matter content in site at IU_3 was significantly different from the rest of the two sites in 2009 and also there was a significant difference in each other site in 2010. Soil P and K values showed a significant difference among the three sites in both years. Soil N content in sites IM_3 and WU_3 were not significantly different in both years, however, was significantly different in the site IU_3. The C:N ratio was also significantly different among all three sites for the two years.

Seed yield: The analysis of variance performed on pooled data set of yield (YIELD) for lupin indicated that only two main effects (location and variety) were statistically significant at $p<0.0001$ (Table 4). The two-way interactive effect between variety and location was also significant at $p<0.0001$. However, effect of year ($p = 0.520$) and interaction between the year and the variety ($p = 0.686$), as well as three-way interaction location, year and variety ($p = 0.904$) were not significant.

Comparatively, higher seed yield was observed for white lupin in IU_3 and WU_3 sites in 2009 and 2010 (Table 5, Fig. 2). Meanwhile, lower seed yield of Kiev Mutant was reported for IM_3 for both years 2009 and 2010 (408 and 385.43 kg ha^{-1}) in all sites in 2009 and 2010 (Table 5). In IM_3, yellow lupin varieties yielded; Pootalong (238.47 for 2009 and 221.52 kg ha^{-1} for 2010) and Wodjil (221.52 for 2009 and 350.22 kg ha^{-1} for 2010). Among the narrow leafed varieties, yield was greater for Gangurru, Tanjil, Madelup were comparatively higher than that of Walan, Belera and yellow lupins, Pootalong and Wodjil in each experimental site.

Table 3: Soil properties and soil nutrient contents (0-30 cm) at the locations selected for the study

	Soil properties and nutrient contents					
Location	pH	Organic matter (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Nitrogen (%)	C:N ration
2009						
Matale (IM_3)	6.83±0.01^{a}	11.55±0.03^{a}	19.66±0.22^{a}	279.36±0.38^{a}	0.50±0.04^{a}	2.31±0.80^{f}
Bandarawela (IU_3)	6.90±0.00^{b}	5.97±0.02^{b}	1.23±0.01^{b}	137.98±0.02^{b}	0.21±0.01^{dc}	2.84±0.67^{dbc}
Nuwara eliya (WU_3)	6.40±0.00^{b}	10.37±0.04^{a}	11.67±0.44^{c}	395.48±2.36^{c}	0.48±0.11^{a}	2.16±0.06^{a}
2010						
Matale (IM_3)	4.83±0.21^{a}	9 .42±0.05^{a}	18.23±0.21^{a}	265.32±0.48^{a}	0.48±0.24^{a}	1.96±0.80^{f}
Bandarawela (IU_3)	5.76±0.03^{b}	6.71±0.32^{b}	2.30±0.22^{b}	135.87±0.02^{b}	0.26±0.23^{dc}	2.58±0.68^{dbc}
Nuwara eliya (WU_3)	6.32±0. 20^{b}	12.42±0.24^{c}	10.67±0.21^{c}	289.46±2.54^{c}	0.56±0.22^{a}	2.21±0.16^{a}

Mean within the same column without a letter in common differ at p = 0.05 using Tukey's hsd, Values are as Mean±SD

Table 4: Summary of the ANOVA for pooled data analysis of year, location and cultivar on yield of lupin varieties grown in different agro ecological regions of Sri Lanka

Source	Sum of squares	df	Mean square	F	p-value
Location (L)	1.80×10^{7}	2	9.02×10^{6}	6.90×10^{2}	0.000
Year (Y)	5.44×10^{3}	1	5.44×10^{3}	4.16×10^{-1}	0.520
Variety (V)	1.72×10^{7}	9	1.91×10^{6}	1.46×10^{2}	0.000
L×Y	1.88×10^{4}	2	9.38×10^{3}	7.17×10^{-1}	0.489
L×V	5.65×10^{6}	18	3.14×10^{5}	2.40×10^{1}	0.000
Y×V	$8.53\text{x } 10^{4}$	9	9.48×10^{3}	7.25×10^{-1}	0.686
L×Y×V	1.39×10^{5}	18	7.74×10^{3}	5.92×10^{-1}	0.904
Error	3.14×10^{6}	240	1.31×10^{4}		

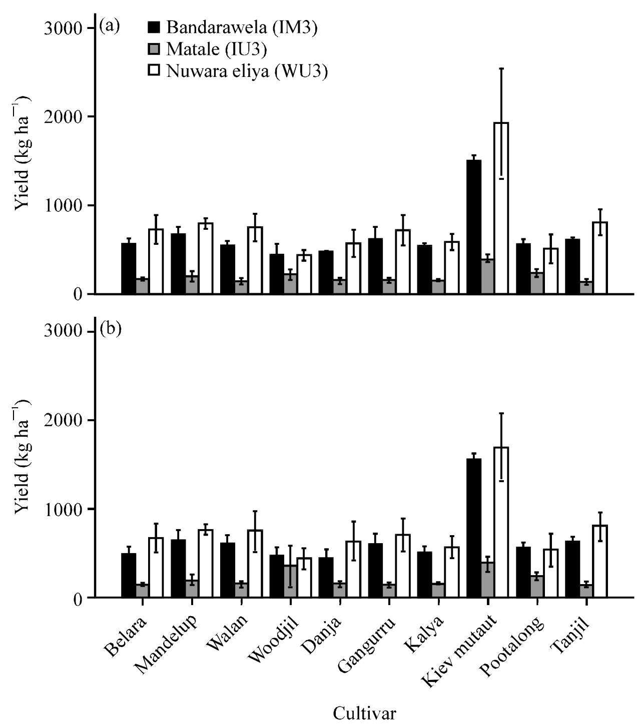

Fig. 2(a-b): Variation of yield of lupin varieties grown in different agro ecological regions of Sri Lanka in (a) 2009 and (b) 2010

Table 5: Least square mean yields of lupin varieties grown in different agro ecological regions in Sri Lanka in 2009 and 2010

	Yield (kg ha^{-1})					
	Bandarawela (IU3)		Matale (IM3)		Nuwara eliya (WU3)	
Variety	2009	2010	2009	2010	2009	2010
Narrow leafed						
Gangurru	620.74^{a}	603.18^{a}	152.40^{a}	146.33^{a}	724.81^{a}	707.36^{a}
Tanjil	620.91^{a}	624.97^{a}	136.81^{a}	145.86^{a}	806.83^{a}	801.87^{b}
Walan	552.10^{b}	609.00^{a}	143.55^{a}	163.49^{b}	750.85^{a}	751.34^{a}
Belera	574.26^{b}	488.27^{b}	168.90^{b}	153.46^{b}	731.90^{a}	677.99^{c}
Danja	482.57^{c}	441.24^{b}	155.12^{b}	155.34^{b}	579.09^{b}	636.34^{c}
Kalya	543.67^{b}	509.04^{c}	162.14^{a}	150.22^{b}	589.87^{b}	570.15^{d}
Mandelup	680.78^{d}	651.25^{d}	198.05^{c}	190.71^{c}	794.70^{c}	758.93^{a}
Yellow						
Pootalong	558.91^{d}	558.87^{c}	238.47^{d}	245.59^{d}	517.93^{b}	536.98^{f}
Woodjil	449.86^{c}	473.94^{b}	221.52^{d}	350.22^{f}	439.63^{d}	443.56^{f}
White						
Kiev mutant	1506.00^{f}	1558.00^{f}	408.31^{f}	385.43^{d}	1931.00^{f}	1697.00^{f}
Error	27.50	32.17	14.72	31.02	85.64	73.41

Mean within the same column without a letter in common differ at p = 0.05 using Tukey's hsd

Table 6: Summary of the ANOVA for pooled data analysis of year, location and variety on biomass production in lupin varieties grown in different agro ecological regions of Sri Lanka

Source	Sum of squares	df	Mean square	F	Sig.
Location (L)	5.43×10^{7}	2	2.71×10^{7}	817.806	0.000
Year (Y)	1.32×10^{5}	1	1.32×10^{5}	3.989	0.047
Variety (V)	1.89×10^{6}	9	2.10×10^{5}	6.327	0.000
L×Y	9.61×10^{4}	2	4.80×10^{4}	1.448	0.237
L×V	2.75×10^{6}	18	1.53×10^{5}	4.604	0.000
Y×V	6.11×10^{5}	9	6.79×10^{4}	2.048	0.035
L×Y×V	7.80×10^{5}	18	4.33×10^{4}	1.306	0.184
Error	7.96×10^{6}	240	3.32×10^{4}		

In summary, yield performances of the lupin cultivars of narrow leafed, white and yellow lupins grown in wet zone upcountry (WU_3), intermediate zone upcountry (IU_3) were comparatively higher than that of intermediate zone mid country (IM_3). Comparatively, the yield in IM_3 was lower than that of IU_3 and WU_3 and IU_3 was lower than the WU_3. The comparison of yield across the lupin varieties between IU_3 and WU_3 revealed that most of the lupin cultivars of three lupin species produce higher yield in wet zone upcountry (WU_3). The varieties of yellow lupin, Woodjil and Pootalong produced comparatively higher yields in IM_3. The cultivars of White lupin, Kiew mutant and narrow leafed lupins, Ganguru, Mandelup and Tanjil yielded better in IU_3. The varieties Kiev Mutant, Tanjil, Mandelup and Walan indicated better yield performance in WU_3.

Biomass production: The analysis of variance performed on pooled biomass data for lupin cultivars grown in different AERs indicated that only two main effect (location and variety) were statistically significant at $p<0.05$ (Table 6). The two-way interactive effect between variety and location was also significant at $p<0.05$. However, effect of year (p = 0.047) and interaction between the year and variety (p = 0.035), as well as three-way interaction location, year and variety (p = 0.184) were marginally significant (Table 6).

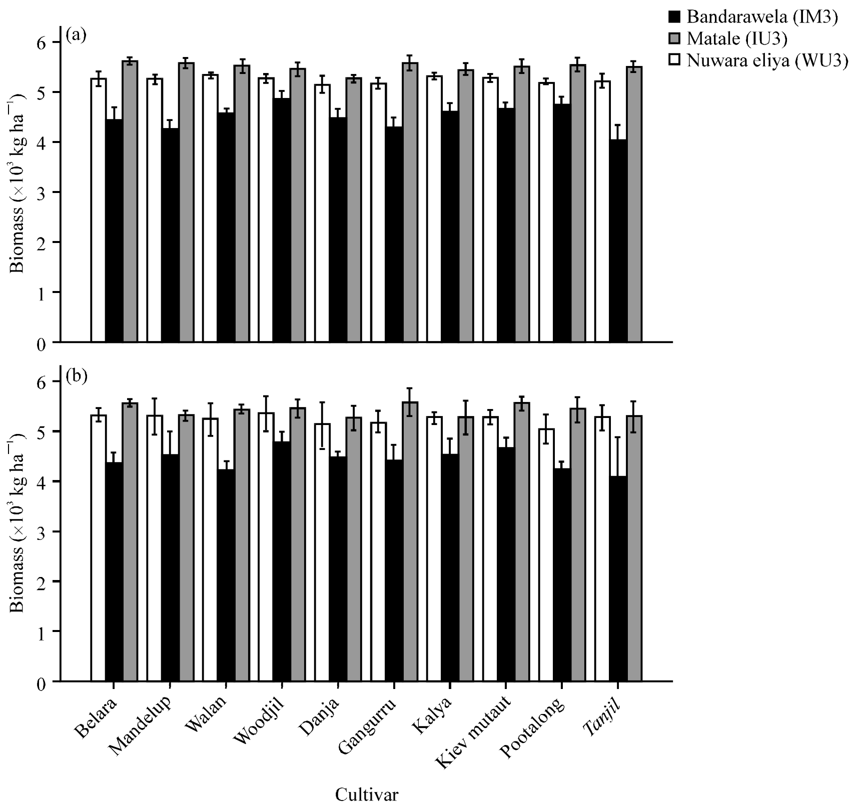

Fig. 3(a-b): Variation of whole plant biomass of lupin varieties grown in different Agro ecological Regions of Sri Lanka in (a) 2009 and (b) 2010

Table 7: Least square mean biomass of lupin varieties grown in different agro ecological regions in Sri Lanka in 2009 and 2010

	Biomass ($\times 10^3$ kg ha^{-1})					
	Bandarawela (IM_3)		Matale (IU_3)		Nuwara eliya (WU_3)	
Variety	2009	2010	2009	2010	2009	2010
Narrow-leafed						
Belara	5.278^{c}	5.340^{a}	4.462^{c}	4.395^{c}	5.623^{c}	5.569^{a}
Mandelup	5.262^{c}	5.328^{a}	4.285^{b}	4.546^{c}	5.578^{d}	5.338^{a}
Walan	5.346^{b}	5.268^{a}	4.577^{c}	4.251^{c}	5.538^{e}	5.444^{a}
Woodjil	5.269^{c}	5.384^{a}	4.869^{g}	4.789^{b}	5.464^{b}	5.474^{a}
Danja	5.154^{a}	5.137^{a}	4.492^{c}	4.467^{c}	5.269^{a}	5.273^{a}
Gangurru	5.178^{c}	5.211^{a}	4.323^{b}	4.436^{c}	5.569^{f}	5.607^{a}
Kalya	5.331^{c}	5.299^{a}	4.600^{d}	4.544^{c}	5.454^{b}	5.302^{a}
Yellow						
Pootalong	5.208^{c}	5.069^{a}	4.777^{f}	4.282^{c}	5.554^{g}	5.457^{a}
Tanjil	5.231^{c}	5.293^{a}	4.069^{a}	4.143^{a}	5.508^{h}	5.316^{a}
White						
Kiev Mutant	5.285^{c}	5.294^{a}	4.677^{e}	4.653^{c}	5.523^{i}	5.578^{a}
Std. Err	0.380	0.101	0.633	0.126	0.427	0.798

Mean within the same column without a letter in common differ at $p = 0.05$ using Tukey's hsd

Variation of whole plant biomass in lupin varieties between three different AERs, IU_3, IM_3 and WU_3 is given in Fig. 3 and Table 7. Comparatively, whole plant biomass of all varieties grown in

IM_3 is lower that of IU_3 and WU_3. Similarly, the highest biomass was occurring in Nuwara Eliya (WU_3). As far as the between site variation in biomsss is concerned, there was a less variation between the IU_3 and WU_3. However, there was a discernible variation between the biomass values between the sites IU_3 and WU_3. In IU_3, the whole plant biomass was higher in varieties Walan, Kalya and Kiev Mutant. The varieties Woodjil, Walan and Kiev Mutant produced a higher biomass in IM_3, meanwhile the varieties Belara, Ganguru and Mandelup showed a higher biomass in WU_3.

DISCUSSION

Lupin (*Lupinus* spp.) is one of the most important crop components suitable for farming systems in Mediterranean area and in South America (Palta *et al*., 2004). It is a pulse crop, rapidly spreading around the world as a protein rich new ingredient of human food and it is widely used as an animal feed (Glencross *et al*., 2003; Dixon and Hosking, 1992). In comparison with major world food crops, lupin exhibit a number of advantages of growing patterns, resilience and ease of harvest, soil N_2 fixing capabilities, digestibility and independency of expensive food processing technologies. Lupins make exceptional human and animal foods, in both raw and processed form. Furthermore, sweet lupin (narrow leafed) is the most economical high-protein crop plant available for marginal soil areas, in both sub-tropical and temperate regions (DAFWA, 2006). Soybean is one of the pulse crops which has gained worldwide commercial reputation over recent years as a food additive, a meat-extender and an ingredient in infant feed. Similarly, sweet lupin can also be used to even greater advantage in the same purposes (DAFWA, 2006). Over the time, lupin may influence food production and agricultural stability in third world countries and is expected to generate scores of nutritional, commercial and industrial products and by-products, targeting to an enormous market potential, as both an available food source and tradable commodity.

The observations of the pot experiment conducted prior to field experiment (Weerakoon and Somaratne, 2010) have clearly demonstrated that the lupin varieties flowered well in WU3 and IU_3. At the flowering stage, L. *luteus* and *L. albus* varieties have taken longer period to flower. Generally, the growth parameters such as stem height at flowering, number of leaves at flowering and number of branches at flowering which were related to flowering showed that lupins are more suitable to grow in WU_3, compared to other two regions included in the study. Similarly, the finding on overall performances of PLBIO and YIELD of lupin varieties revealed that best performance was reported for WU_3 followed by IU_3. Out of the seven varieties of *L. angustifolius*, Tanjil, Mandelup and Walan performed well, indicating that these lupin varieties are more suitable to Sri Lanka's climatic conditions.

The field experiments which were conducted with ten commercially cultivated *Lupinus* genotypes comprising of *L. albus* (white lupin), *L. luteu*s (yellow lupin) and *L. angustifolius* (narrow leafed, sweet lupin) varieties indicated that the performance of the three varieties varied considerably in different AERs. The seedling stage data (not included) have also shown that lupin varieties were better acclimating to the regions WU_3 and IU_3. At flowering stage, *L. luteus* and *L. albus* varieties have taken longer period to flower than that of *L. angustifolius*. The regions WU_3 and IU_3 recorded average temperatures of 16 and 20°C, respectively during lupin flowering. This situation has contributed much to the great success in flowering and pod formation as well as the high seed yield in lupin varieties compared to that of region IM_3. The average temperature in IM_3 region at flowering was 25°C which would have had a negative effect on successful flowering and pod setting (GRDC, 2008).

Vernalization is a physiological process by which certain plant species produce flower after prolonged exposure to cooling temperatures. The duration of exposure and the level of temperatures will affect the flowering time. A continuous variation in vernalization requirement and response in various *Lupinus* species and their genotypes has been reported (Rahman and Gladstones, 1974; Huyghe, 1991; Putnam *et al.*, 1993; Clapham and Willcott, 1995; Landers, 1995). The combined effect of both vernalization and long days always resulted in the shortest time to flowering. The effect of day length was most pronounced in the thermo-sensitive varieties. In the non-vernalized thermo-neutral varieties, time to flowering was reduced by 10-21 days (Christiansen *et al.*, 2000). The selected lupin varieties in this study were non-vernalized thermo-neutral varieties which are growing in Western Australia. Therefore, there was no apparent difference in flowering time among the three sites used for field studies.

The seed yield was ranged from higher in WU_3 followed by IU_3 and lower in IM_3. The plant biomass was greater in Belara followed by Mandelup and Tanjil in the AERs WU_3 and IU_3. The result of the present study agreed with the finding of the study of (Palta *et al.*, 2004) in which yield performance of *L. angustifolius* varieties, Tanjil and Belara grown in Western Australia reported a higher biomass and seed yield than other varieties.

Lupin has an intermediate growth habit, with a major vegetative growth after flowering, characterized by the production and growth of apical branches and pods (Palta *et al.*, 2004). It is therefore not surprising that the biomass production and yield produced in lupins grown in areas such as IM_3 with high atmospheric temperature (ca. 25°C) was low The high temperature prevailed in IM_3 during flowering may have contributed to poor yield performance of *Lupinus* varieties in IM_3. compared to that of WU_3 and IU_3. Further, the soil properties of three selected sites in the AERs signify that nutrient status of soil at site in IM_3 was poor compared to other two sites, IU_3 and WU_3. The high content of soil Potassium at site in WU_3 and IU_3 could be related to the increased flowering followed by high seed yield. Similarly, the rich SOC and other soil nutrients apparently contributed the successful growth of lupins in WU_3 and IU_3. Comparatively higher SOC contents immobilize nitrogen and plant-available-nutrients and gradual release of these nutrients during the decomposition will provide an ample source of nutrients to the plants. Further, lower temperature and fluctuation of soil moisture contents in these sites govern the decomposition process of SOC and sustain the slow release of soil nutrients. Optimum range of soil pH required for successful growth in lupins is in the rage of 5.0-7.0 (Drake, 2008). The soil pH values observed in sites, WU_3, IU_3 and IM_3 are 6.4, 6.8 and 6.9, respectively. The negative correlation between the agro-morphological characters and soil pH explained the influence of soil pH on lupin growth. The lower pH values in soil facilitate the availability of nutrients which are immobilized. Lupin is an excellent rotation crop because of its nitrogen-fixing qualities (GRDC, 2006). In addition, lupins can increase soil phosphorus availability to subsequently growing crops. Cereal and crop yields are higher after lupin as they fix nitrogen and improve soil conditions (GRDC, 2006). Lupin plants produce special ribosomes that are able to neutralize acidic soil and as the plants grow, chemicals are released into the soil to condition it. The dead lupin plants can be added to compost to help creating a more balanced fertilizer base (Wieland *et al.*, 1997; Gallaher, *et al.*, 1997).

Though, it is a small island, Sri Lanka possesses varying climatic conditions and certain climatic condition represents more or less that of Mediterranean and South American climatic conditions. The results of the field experiment indicated that out of the three experimental sites situated in three AERs, only two regions, WU_3 and IU_3 can be recommended for lupin growing. The varieties, Tanjil, Walan, Belera, Mandelup and Kiev Mutant produced higher yield at WU_3 followed by IU_3 and they could be recommended for growing as a pulse crop in WU_3 and IU_3. However, it is worthwhile to conduct further field experiments in WU_3 and IU_3 to assess the economical feasibility of growing selected *L. angustifolius* varieties as a supplementary protein source. Similarly, the varieties of *L. luteus* and *L. albus* need to be further assessed to develop as a livestock/poultry feed as well as green manure.

From the field experiments it could conclude that lupin varieties are well growing in WU_3 and IU_3. Growth and yield performance of *L. albus* (white lupin), *L. luteus* (yellow lupin) and *L. angustifolius* (narrow-leafed, sweet lupin) varied across the AERs. The seedlings of lupin varieties were better acclimatized to the regions WU_3 and IU_3. The variation of temperatures in the range of 16 and 20°C is a crucial requirement for successful flowering and pod setting in WU_3 and IU_3. The soil nutrient status and soil organic matter are important factors for successful growth of lupins in WU_3 and IU_3. The variation of soil pH influences growth and yield performance of lupin. Additional field studies are required for a better understanding of the impact of eco-climatic conditions on the growth and yield performance of lupins in Sri Lanka.

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