សណ្ឋានដីបាសាល់នៅភាគខាងកើតនៃប្រទេសកម្ពុជា បានផ្តល់នូវកាលានុវត្តភាពយ៉ាងច្រើន សម្រាប់បង្កើននូវផលិតកម្មដំណាំចម្ការ

Field Crop Productivity in Relation to Soil Properties in Basaltic Soils of Eastern Cambodia

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សណ្ឋានដីបាសាល់ នៅភាគខាងកើតនៃប្រទេសកម្ពុជា បានផ្តល់នូវកាលានុវត្តភាពយ៉ាងច្រើន សម្រាប់បង្កើននូវផលិតកម្មដំណាំចម្ការ ប៉ុន្តែទិន្នន័យនៃការពិសោធន៍ស្រាវជ្រាវទាក់ទងទៅនឹងពេលវេលាដាំដុះ និងប្រភេទដីលើដំណាំចម្ការនៅតំបន់នេះ នៅមានកម្រិតនៅឡើយ។ ការសិក្សាស្រាវជ្រាវនេះ មានគោលបំណងដើម្បីកំណត់នូវដំណុះការលូតលាស់ និងទិន្នផលនៃដំណាំពោត សណ្តែកបាយ សណ្តែកដី ល្ង និងសណ្តែកសៀងនៅលើដីស្រែចម្ការកសិករ ដែលទាក់ទងទៅនឹងពេលវេលានៃការដាំដុះ (ដើមរដូវវស្សា ឬពាក់កណ្តាលរដូវវស្សា) ប្រភេទ និងលក្ខណៈសម្បត្តិរបស់ដី នៅលើសណ្ឋានដីបាសាល់ភាគខាងកើតនៃប្រទេសកម្ពុជា។ ពិសោធន៍ជាច្រើនបានធ្វើនៅក្នុងស្រុកអូរាំងឪ ក្នុងរយៈពេលពីរឆ្នាំដែលមានរបបទឹកភ្លៀងប្រចាំឆ្នាំខុសគ្នា។ សណ្តែកដីជាដំណាំដែលមានភាពសមស្របជាងគេបំផុតដោយសារមានដំណុះល្អទាំងនៅដើមរដូវ និងពាក់កណ្តាលរដូវវស្សា និងអាចទទួលបានទិន្នផលនៅលើទីតាំង៨០% នៃទីកន្លែងពិសោធន៍ទាំងអស់។ ទិន្នផលខ្ពស់ជាប់ៗគ្នានៃសណ្តែកដីទទួលបាននៅលើក្រុមដីកំពង់សៀម (២,១-៣,៤ ត/ហត) ប៉ុន្តែទិន្នផលនៅពាក់កណ្តាលរដូវវស្សា មានការធ្លាក់ចុះជាមធ្យម ០,៥ ត/ហត ដែលអាចបណ្តាលមកពីការជាំទឹកខ្លាំង។ នៅលើក្រុមដីអូរាំងឪ និងឡាបានសៀកទិន្នផលសណ្តែកដីមានការប្រែប្រួលទៅតាមទីកន្លែងពិសោធន៍ និងរដូវកាល ប៉ុន្តែជាទូទៅនៅឆ្នាំ២០០៥ ទទួលបានទិន្នផលខ្ពស់ជាងឆ្នាំ២០០៤។ ការនេះប្រហែលជានៅក្នុងឆ្នាំ២០០៥ មានភាពជាំទឹកតិចជាង។ ផ្ទុយពីនេះសណ្តែកសៀង បានទទួលបរាជ័យបើដាំក្នុងដើមរដូវវស្សាដោយសារមានដំណុះខ្សោយ និងទិន្នផលទាប។ នៅពាក់កណ្តាលរដូវវស្សា ទិន្នផលនៃសណ្តែកសៀងនៅលើក្រុមដីកំពង់សៀមទទួលបានរហូតដល់ ៣,៣ ត/ហត។ ទិន្នផលសណ្តែកសៀងនៅពាក់កណ្តាលរដូវវស្សាដូចគ្នាទៅនឹងសណ្តែកដីដែរ គឺមិនមានស្ថេរភាពទេនៅលើក្រុមដីអូរាំងឪ និងឡាបានសៀក។ សណ្តែកបាយមិនទទួលបានទិន្នផលទេ នៅលើទីតាំង ៦៣% នៃទីកន្លែងពិសោធន៍ដើមរដូវវស្សា ប៉ុន្តែនៅលើក្រុមដីកំពង់សៀម និងអូរាំងឪ បើសិនដំណាំមានដំណុះល្អ វាអាចផ្តល់ទិន្នផលពី០,៩-១,៣ ត/ហត។ នៅលើដីដូចគ្នានេះដែរ នៅពាក់កណ្តាលរដូវវស្សា សណ្តែកបាយផ្តល់ទិន្នផលពី០,២-១,៥ ត/ហត។ ការបរាជ័យនៃសណ្តែកបាយ នៅលើក្រុមដីឡាបានសៀក ទាំងដើមរដូវ និងពាក់កណ្តាលរដូវវស្សាក្នុងឆ្នាំ២០០៤ និងឆ្នាំ២០០៥ គឺមួយផ្នែកបណ្តាលមកពីភាពអាស៊ីតនៃដី។ ការលូតលាស់នៃដំណាំពោតក៏មិនមានស្ថេរភាពដែរ។ ជាង៥០% នៃដំណាំដែលបានដាំដុះក្នុងឆ្នាំ២០០៥ ត្រូវទទួលបរាជ័យដោយសារមានការរាំងស្ងួតដែលធ្វើឱ្យមានដំណុះត្រាប់ និងការចាប់ផ្តើមលូតលាស់ខ្សោយ។ ទិន្នផលសណ្តែកបាយទទួលបានរហូតដល់ ៤,៥ ត/ហត នៅលើដីឡាបានសៀក ក្នុងឆ្នាំ២០០៤ ប៉ុន្តែមិនទទួលបានទិន្នផលទេ នៅលើក្រុមដីដូចគ្នាក្នុងឆ្នាំ២០០៥។ ភាពរាំងស្ងួត ភាពអាស៊ីតនៃដី និងកង្វះជីអាសូតត្រូវបានគិតថាជាកត្តាចម្បង ដែលធ្វើឱ្យការលូតលាស់របស់ដំណាំពោតមិនបានល្អ។ ទិន្នផលខ្ពស់នៃដំណាំទាំងអស់លើកលែងតែដំណាំល្ងអាចសម្រេចបាន ប៉ុន្តែវាមានការប្រែប្រួលក្នុងចំណោម ប្រភេទដី ទីកន្លែង និងរដូវកាល។ ការធ្វើឱ្យបានជោគជ័យលើភាពមិនសមស្របនៃការលូតលាស់របស់ដំណាំ គឺ

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ជាគន្លឹះ ដើម្បីកាត់បន្ថយហានិភ័យទាក់ទងទៅនឹងផលិតកម្ម ដំណាំចម្ការនៅលើដីបាសាល់ ។

Abstract

The basaltic landscapes of eastern Cambodia offer opportunities for increased production of non-rice crops but there is limited experimental data on the performance of these crops in relation to sowing season and soil types. The objective of the present study was to determine the emergence, growth and yield of maize, mungbean, peanut, sesame and soybean in farmers' fields in relation to time of sowing (early wet season, EWS or main wet season, MWS), soil types and soil properties in the basaltic landscapes of eastern Cambodia. Experiments were conducted in Ou Reang Ov district during two years with contrasting rainfall. Peanut was the most reliable crop with successful establishment in both EWS and MWS, and harvestable yield at 80% of sites. Consistently high peanut yields were obtained on Kompong Siem soils (2.1-3.4 t/ha), but MWS yields were depressed on average by 0.5 t/ha, possibly due to greater waterlogging. On Ou Reang Ov and Labansiek soils, peanut yields varied with site and season, but were generally higher in 2005 than 2004, again possibly due to lower waterlogging prevalence. By contrast, soybean failed on all occasions in the EWS either due to lack of crop establishment or yields that were too low to justify growing this crop. In the MWS, soybean yields of up to 3.3 t/ha were attained on Kompong Siem soils. Like peanut, soybean yields in the MWS were inconsistent on the Ou Reang Ov and Labansiek soils. Mungbean failed to produce harvestable yield on 63% of EWS sites, but on Kompong Siem and Ou Reang Ov soil, if establishment was successful, mungbean produced grain yield of 0.9-1.3 t/ha. On the same soils in the MWS, mungbean yields were 0.2-1.5 t/ha. Mungbean failure on Labansiek soils, in both EWS and MWS in 2004 and 2005 was attributed to soil acidity. Maize was inconsistent in its performance. Over 50% of sowings in 2005 failed due to drought which caused poor crop emergence and establishment. Yields up to 4.5 t/ha were obtained on Labansiek soils in 2004, but no yield was obtained in the same soil type in 2005. Drought, soil acidity and inadequate N fertilizer are suggested to be the main factors accounting for the unreliable performance of maize. High yields of all crops except sesame were achievable but actual yields were variable among soils, sites and season. Overcoming the unreliable performance of crops is the key to decreasing the risk associated with non-rice crop production on the basaltic soils.

Introduction

In Cambodia, there is considerable scope for developing upland crops and cropping technologies. Upland areas are widespread throughout the Kingdom and generally under utilized. In 2004-5, non-rice field crops represented only about 13% of the total cropped area in Cambodia (MAFF 2005). With improved security and road access in rural Cambodia, opportunities for crop diversification and increased household income of farmers exist through rainfed cropping in the uplands, in both the EWS and MWS.

Basaltic geology of mid-Pleistocene age is prevalent in Cambodia covering large areas in Kampong Cham, Kampong Thom, Kratie, Mondulkiri, and there are significant occurrences of it in Battambang, Prey Vihear, and Ratankiri (Workman 1972). The soils associated with these occurrences of basalt have not been comprehensively mapped and described. However, Hin et al. (2006, 2007) described the basaltic soils of Ou Reang Ov and Ponhea Krek districts in Kampong Cham province and developed a soil-landscape model for predicting soil types associated with basaltic plateaux. On the gently undulating landform elements on top of the plateau, the Labansiek Soil Group (White et al. 1997) was prevalent. The majority of these soils in Ou Reang Ov district, as in other parts of Kampong Cham, are occupied by rubber. The deep friable nature of these soils provides adequate soil water storage for rubber to survive over the long dry season, and rubber being acid tolerant (Dierolf et al. 2001) is able to grow productively on Labansiek soils. On the slopes of the basaltic plateau are brown gravelly loam soils, not previously described among the rice soil groups of Cambodia (White et al. 1997). The soils of this landform element, which are now called the Ou Reang Ov Soil group, are unsuitable for rice on account of slope, and free drainage (Seng et al. 2007). Similar occurrences of the brown gravelly soil group on the slopes of basaltic plateaux have been observed elsewhere in Kampong Cham, and in Kampong Thom. The Ou Reang Ov Soil group is shallow compared to Labansiek, and this combined with the high gravel content of the sub-soil makes it unsuited to rubber production. On the gentle lower slopes of the basaltic plateau and the adjacent colluvial-alluvial plains, dark clay soils belonging to the Kompong Siem Soil group dominate. In the lower lying portions of this plain, the risk of inundation and waterlogging are so great that rice production is the dominant land use. On the slightly higher elevations close to the slopes of the basaltic plateau, the Kompong Siem soil is better drained and capable of producing field crops apart from rice.

Kampong Cham province already has a relatively diversified crop production, and is a leading province in production of many non-rice crops in Cambodia such as soybean, mungbean, rubber, cassava, peanut, sesame and sugarcane (MAFF 2005). Nevertheless there is limited experimental data on the performance of non-rice crops on the prominent soils of this province. The objective of the present study was to determine the emergence, growth and yield of maize, mungbean, peanut, sesame and soybean in farmers' fields in relation to time of sowing (EWS or MWS), soil types and soil properties in the basaltic landscapes of eastern Cambodia. Experiments were conducted in Ou Reang Ov district of Kampong Cham province for two years (2004, 2005).

Materials and Methods

Sites and soil types

There were 3-4 sites per season located in Ou Reang Ov district, Kampong Cham province (Table 1). Soil profiles were inspected and described in detail at most sites and soil chemical characterization was carried out on at least one site of each Soil group (Hin et al. 2006). If the experiments were repeated on the same soils in both seasons, different sites were used, but usually on an adjacent or close-by location.

Land preparation and sowing

The experimental fields were ploughed (20-30 cm deep) and leveled to control water movement. Drains were constructed around the experiment to remove excess water from the field. After harrowing, beds 10 m long x 1.5 m wide x 0.15 m high were installed. In the MWS, a drain of 15 cm depth was dug around each bed and the soil material heaped on the bed to raise its level for improved drainage. In the EWS, only a shallow 10 cm drain around the bed was set up.

All crop varieties received the following rates of fertilizer nutrients in 2004 and 2005 (as modified from Dierolf et al. 2001; and CIAP 1999): N, 115 (as urea); P, 29 (as di-ammonium phosphate); 28 K (as KCl); 13 S (as 16-16-8-13); Zn, 5 (as $ZnSO_4$); Cu, 1.25 (as $CuSO_4$); Mo, 0.3 (as MoO_3); B, 0.82 (as H_3BO_3). All numbers are expressed in kg/ha of nutrient element.

After installing seeding beds, 50% of N and K and all of the remaining fertilizers were applied by spreading evenly, and then incorporated by hoeing (0-10 cm) into soil. These fertilizers were applied 48 hours before sowing seed. The remaining 50% of N (as urea) and K (as KCl) were top-dressed within 3-4 weeks after sowing. Top-dressing of fertilizer was carried out after weeds had been removed.

The experiment plots were arranged in a randomized complete block design with 5 crop varieties and 4 replications making a total of 20 plots at each location. Trials were sown in the EWS (May-August) and in the MWS (July-October), in 2004 and 2005 (Table 1). Since there was no access to supplementary irrigation at the sites, crops relied completely on rainfall. This necessitated variations in time of sowing among sites (Table 1).

Maintenance of crops

All experimental fields were kept free of weeds and insects during crop growth. No herbicide was used to control weeds. Weeds were removed by hand, especially during early establishment of crops. Pesticide was used to control insect pests as required.

Inter-row tillage was carried out 3-4 weeks after sowing by hand for weed control, and at the same time, plants were thinned to leave only 1 plant per hill.

Data collection

At each site in 2004, soil samples were taken from 0-15 cm and 15-30 cm depth before fertilizer application and after harvesting of crops. Soil samples were air dried, crushed to remove any plant residue, and sieved to pass through a 2-mm sieve. Soil analysis was con-

Table 1. Site details for on-farm trials in the early wet (EWS) and main wet season (MWS) of 2004 and 2005 in Ou Reang Ov district, Kampong Cham province

Seasons	Soil survey site[A]	Soil group	Date of sowing	Location
		2004		
EWS	Site 13	Kompong Siem	23 May 2004	Toul Thkov village, Preah Thiet commune
EWS	Site 14	Ou Reang Ov	23 May 2004	Stung village, Toul Sophy commune
EWS	Site 18	Ou Reang Ov	23 May 2004	Chamcar Kor village, Chork commune
EWS	Site 15	Labansiek	23 May 2004	Toul Sophy village, Damnak Keo commune
MWS	Site 10/13	Kompong Siem	18 July 2004	Toul Phnov village, Ampel Tapopk commune
MWS	Site 11	Ou Reang Ov	19 July 2004	Preah Tiet commune
MWS	Site 17	Ou Reang Ov	30 July 2004	Chamcar Kor village, Chork commune
MWS	Site 16	Labansiek	18 July 2004	Sre Spey village, Kong Chey commune

2005				
EWS	Site 13	Kampong Siem (non-gravelly)	31 May 2005	Ul Sieng, Toul Thkov village, Preah Tiet commune
EWS	Site 14	Ou Reang Ov	29 April 2005	Linh Lon, Stung village, Toul Sophy commune
EWS	Site 17	Ou Reang Ov	26 May 2005	Ear Ben, Chamcar Kor village, Chork commune
EWS	Site 15	Labansiek	04 June 2005	Tbong Khmum district
MWS	Site 13	Kampong Siem (non-gravelly)	23 July 2005	Ul Sieng, Toul Thkov village, Preah Tiet commune
MWS	Site 11	Ou Reang Ov	23 July 2005	Long Chhem, Preah Tiet commune
MWS	Site 17	Ou Reang Ov	28 July 2005	Ear Ben, Chamcar Kor village, Chork commune
MWS	Site 16	Labansiek	3 Aug 2005	Tbong Khmum district

[A] Site numbers refer to Hin et al. (2006).

ducted according to Rayment and Higginson (1991) for: pH ($CaCl_2$); organic C; N (total and inorganic forms); Colwell P; KCl-40 extractable S; DTPA extractable Cu, Zn, Mn, Fe; hot water soluble B; exchangeable Ca, Mg, Na, K, and Al.

Before sowing, seed of all crops was checked for high germination percentage in the laboratory. One week after sowing in the field, seed emergence was determined by randomly selecting 5 hills per plot/bed and the number of established plants counted. These sampling hills were also used to determine plant density (number/m^2) at harvest.

Time of 50 % flowering and 50 % podding were noted and scoring of insect pest damage, weeds, disease (data not shown), and nodulation were recorded at flowering.

Dry matter of shoots at harvest and yield of pods and seeds were determined by randomly sampling 15 plants per plot. Total seed yield per plot (pod yield for peanut) was also determined at maturity by harvesting all plants in the net plot. After seed weight was recorded, seed samples were taken to assess 1000-seed weight, except for sesame.

Daily rainfall data were recorded at several trial sites in 2004 and 2005, using rain gauges at the experimental sites.

Results

Rainfall analysis

Rainfall was recorded throughout the growing season in 2004 for Sites 13, 14 in the EWS, and Sites 11, 16 in the MWS (Fig. 1). The earliest maturing crop, mungbean, received 400-800 mm rainfall from sowing to harvest which was generally below the optimum amount of 750 mm, but above 400 mm, the threshold rainfall which causes severe yield inhibition (Sys et al. 1993). By contrast, for peanut which had a growth

Crops were sown with the following methods:

Crop	Spacing (cm)	Depth of seeding (cm)	Number of seed per hole
Mungbean	30 x 10	2	3
Soybean	30 x 10	3	3
Maize	60 x 20	3	3
Peanut	30 x 10	5	3
Sesame	60 x 10	1	3

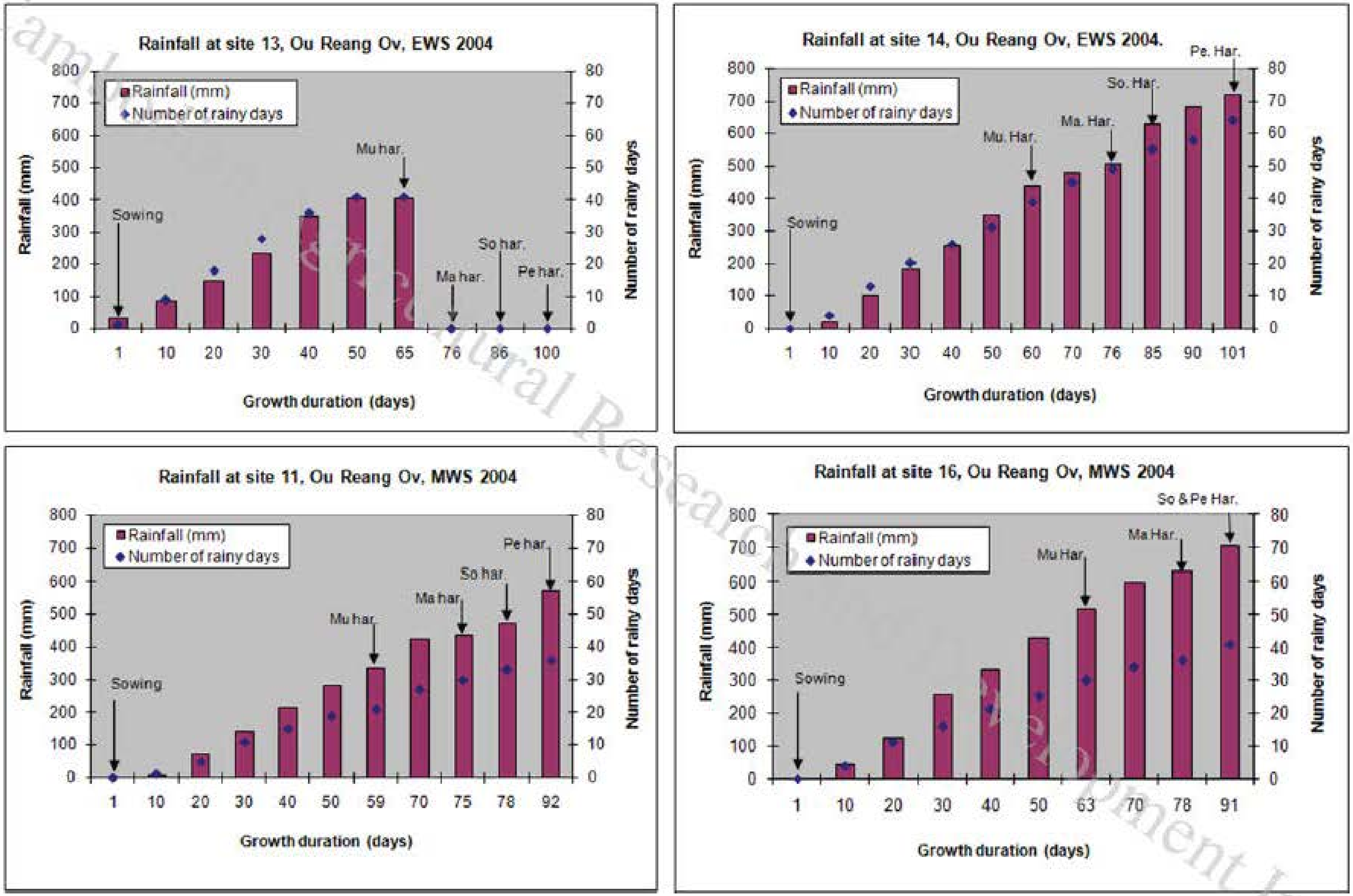

Figure 1. Seasonal rainfall (mm and number of rainy days) for mungbean (Mu), maize (Ma), peanut (Pe), sesame (Se) and soybean (So) in 2004 trials in Ou Reang Ov district in the early wet (EWS) and main wet seasons (MWS). Note there were no rainfall records at Site 13 after day 65.

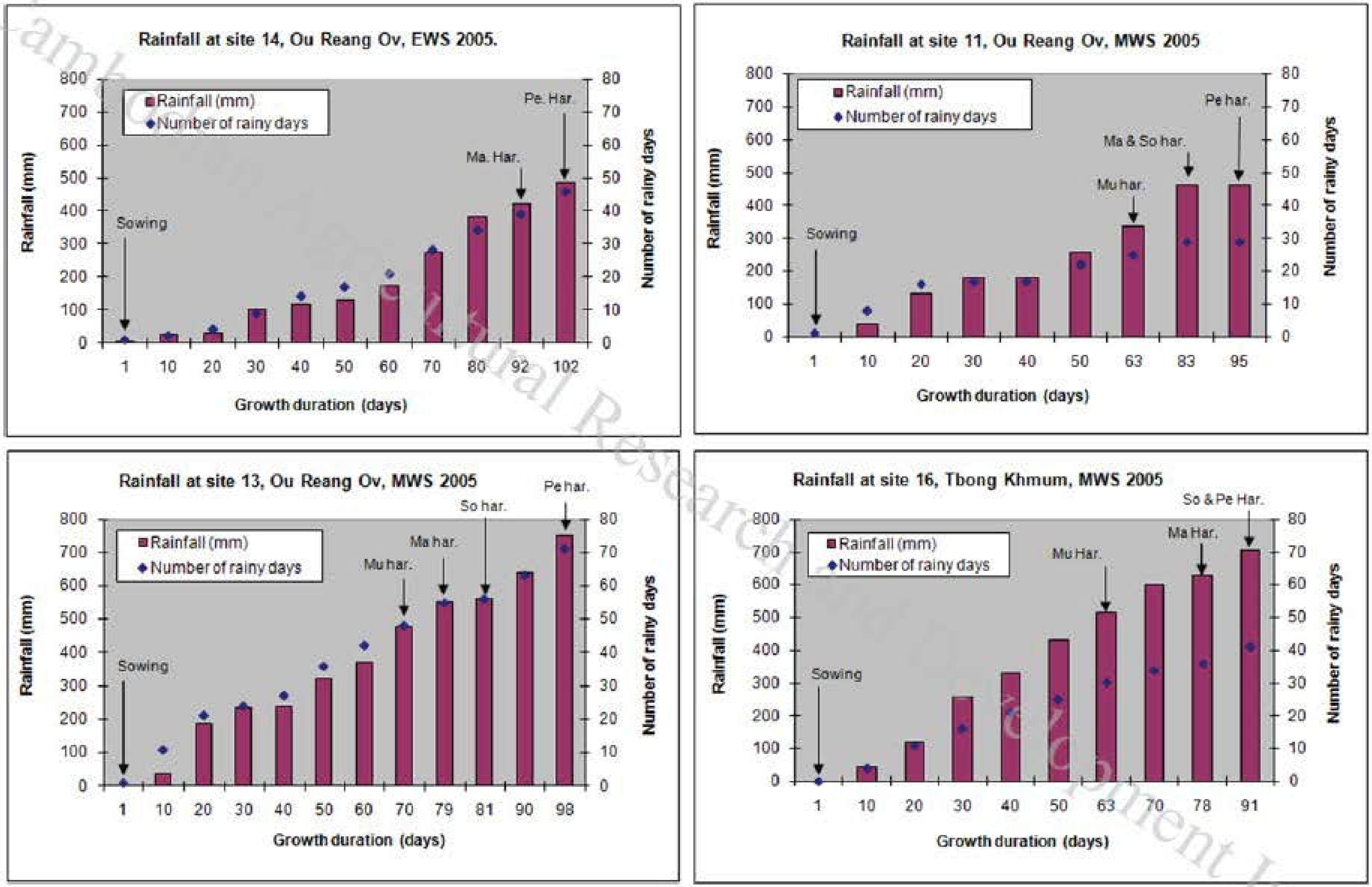

Figure 2. Seasonal rainfall (mm and number of rainy days) for mungbean (Mu), maize (Ma), peanut (Pe), sesame (Se) and soybean (So) in 2005 trials in Ou Reang Ov district in the early wet (EWS) and main wet seasons (MWS).

Table 2. Soil analysis from sites of on-farm trials in 2004. Samples taken before sowing (B) and after harvesting (A)

Season	Soil Group	Site No.	Depth (cm)	Sampling	NO_3-N mg/kg	NH_4-N mg/kg	P mg/kg	Exch K cmol/kg	KCl40-S mg/kg	Org C %	Total N %	pH $CaCl_2$	DTPA Mn mg/kg	DTPA Zn mg/kg	B H_2O mg/kg
EWS	Ou Reang Ov	14	0-15	B	15	16	151	0.78	10.6	2.07	0.17	5.7	106	4.53	0.3
EWS	Ou Reang Ov	14	0-15	A	8	13	141	0.46	9	2.21	0.19	5.5	107	5.29	0.4
MWS	Ou Reang Ov	11	0-15	B	2	14	57	0.45	10	1.62	0.14	4.9	110	10	0.3
MWS	Ou Reang Ov	11	0-15	A	3	18	134	1.42	11	1.82	0.16	5.9	111	5.33	0.3
MWS	Ou Reang Ov	17	0-15	B	7	12	76	0.21	8.5	1.32	0.13	5.1	121	4.63	0.3
MWS	Ou Reang Ov	17	0-15	A	2	10	83	0.11	5.8	1.14	0.11	5.3	49	3.57	0.2
EWS	Ou Reang Ov	14	15-30	B	1	10	79	0.11	5.1	0.85	0.08	5.8	22	0.9	0.2
EWS	Ou Reang Ov	14	15-30	A	4	11	83	0.2	14.2	1.22	0.12	5.3	65	1.99	0.3
MWS	Ou Reang Ov	11	15-30	B	1	12	84	0.23	7.3	1.49	0.11	4.5	136	5.3	0.3
MWS	Ou Reang Ov	11	15-30	A	1	13	62	0.37	10.1	0.91	0.1	4.8	62	1.2	0.2
MWS	Ou Reang Ov	17	15-30	B	5	11	109	0.12	6.7	1.06	0.11	5.2	66	1.37	0.3
MWS	Ou Reang Ov	17	15-30	A	6	10	112	0.12	5.5	0.95	0.10	5.2	52	1.18	0.3
EWS	Kompong Siem	13	0-15	B	1	11	12	0.09	4.9	1.02	0.09	5.7	70	0.7	0.2
EWS	Kompong Siem	13	0-15	A	1	10	18	0.16	6.8	1.15	0.09	5.5	105	1.93	0.3
MWS	Kompong Siem	13	0-15	B	1	16	19	0.16	7.4	1.2	0.12	5.8	82	1.03	0.3
MWS	Kompong Siem	13	0-15	A	1	12	3	0.08	6.6	1.13	0.10	5.5	100	1.61	0.3
EWS	Kompong Siem	13	15-30	B	1	9	9	0.04	3.5	0.71	0.07	6.0	32	0.37	0.2
EWS	Kompong Siem	13	15-30	A	2	9	8	0.07	6	0.77	0.07	6.7	39	0.63	0.3

MWS	Kompong Siem	13	15-30	B	1	5	6	0.07	4.9	0.44	0.04	5.8	127	0.33	0.1
MWS	Kompong Siem	13	15-30	A	2	9	8	0.05	5.9	0.71	0.07	6.5	40	0.48	0.2
EWS	Labansiek	15	0-15	B	21	13	43	0.22	13.2	1.34	0.13	4.7	179	1.63	0.3
EWS	Labansiek	15	0-15	A	5	16	39	0.21	11.4	1.32	0.14	4.7	216	1.61	0.7
MWS	Labansiek	16	0-15	B	2	17	45	0.36	6.7	1.46	0.14	5.3	169	3.48	0.4
MWS	Labansiek	16	0-15	A	3	12	49	0.25	15	1.48	0.14	4.5	156	2.37	0.6
EWS	Labansiek	15	15-30	B	14	12	49	0.12	12.9	0.88	0.1	4.7	98	0.47	0.3
EWS	Labansiek	15	15-30	A	20	14	28	0.14	13.7	1.04	0.12	4.5	113	0.89	0.4
MWS	Labansiek	16	15-30	B	3	14	39	0.22	14.3	1.09	0.11	5.1	133	1.94	0.4
MWS	Labansiek	16	15-30	A	23	8	48	0.12	11.2	0.88	0.10	4.9	92	0.42	0.3

Seed of the following species and varieties were used for the on-farm trials:

Species	Variety	Seed source
Mungbean (*Vigna radiata*)	Cardi Chey	CARDI
Soybean (*Glycine max*)	DT84	Kbal Koh Research Station
Maize (*Zea mays*)	Composit	Kbal Koh Research Station
Peanut (*Arachis hypogaea* L.)	Local variety	Local market
Sesame (*Sesamum indicum* L.)	Local variety (white)	Local market

duration of 92-103 days, cumulative rainfall received was 700-800 mm except at Site 16 where only 450 mm was recorded. All these amounts of rainfall are considered optimal for peanut (Sys et al. 1993). Soybean received adequate rainfall at Sites 13 and 14 in the EWS, but had less than optimal rainfall in the MWS at Site 16.

In general the number of rainfall-days and total in-season rainfall for crops was less in the 2005 season than 2004, especially in the early part of the season (Fig. 2).

Soil analysis

Soil analysis was only conducted on soils from the 2004 experimental sites. In general, this will reflect the properties of the 2005 trial sites since they were located nearby, except for Site 15 which was in a different district and was more severely acid than Site 15 used in 2004.

Organic carbon levels were highest in Ou Reang Ov soils and lowest in Kompong Siem soils. Total N levels followed the same pattern. Ou Reang Ov and Labansiek soils had reasonable amounts of NH_4-N available before sowing (equivalent to about 30-40 kg N/ha), but Kompong Siem had lower levels especially in the 15-30 cm layer. In general, the NO_3-N levels were much lower than for NH_4-N, except on Sites 15 and 16 of Labansiek and Site 14 of Ou Reang Ov soils.

Lowest pH ($CaCl_2$) values were obtained on Labansiek soils: the most acid values, at Site 15, were, about 4.7. Site 11, classified as Ou Reang Ov soil also had low pH ($CaCl_2$), especially at 15-30 cm. Low pH ($CaCl_2$) was associated with high extractable Mn (Table 2) (Hazelton and Murphy 2007), but none of the acid soils contained significant levels of exchangeable Al (data not shown). Kompong Siem soil was only moderately acid (pH ($CaCl_2$) > 5.5).

Exceptionally high extractable P levels were found in the Ou Reang Ov soils, even before fertilizer was applied. The levels in Labansiek soils were > 30 mg P/kg and hence probably adequate for crop growth. By contrast, the Kompong Siem had low extractable P levels (Peverill et al. 1999).

Kompong Siem soils had low and potentially deficient exchangeable K levels (Peverill et al. 1999). Exchangeable K levels in Ou Reang Ov soil were more than adequate for plant growth at Sites 14 and 17, but marginal at Site 11. Labansiek soils had marginal exchangeable K levels in the topsoil and lower levels in the 15-30 cm layer.

Table 3. Field emergence (% of sown seeds) at 2-3 weeks after sowing of crops in the early (EWS) and main wet seasons (MWS). Values are means of four replicates

Sites	Soil group	Maize		Mungbean		Soybean		Peanut		Sesame	
		2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
	EWS										
13	Kompong Siem	72	0	67	89	68	0	62	97	0	0
17	Ou Reang Ov	0	62	0	0	0	0	0	98	0	0
14	Ou Reang Ov	74	60	80	0	48	0	89	93	0	0
15	Labansiek	67	0	0	0	0	0	0	90	0	0
LSD (p<0.05)		*11.1*	*9.0*	*11.3*	*13.4*	*9.9*	*5.3*	*8.9*	*5.1*	-	-
	MWS										
13	Kompong Siem	82	97	85	97	75	98	87	75	0	0
11	Ou Reang Ov	79	88	73	88	72	95	73	73	0	0
17	Ou Reang Ov	85	0	79	77	75	72	78	65	0	0
15	Labansiek	0	0	0	0	0	0	0	97	0	68
16	Labansiek	85	0	75	0	75	0	80	0	0	0
LSD (p<0.05)		*11.5*	*7.6*	*10.5*	*11.7*	*13.1*	*12.6*	*11.5*	*10.7*	-	*10.1*

Levels of extractable S were low enough on Kompong Siem soil to induce deficiency without S fertilizer (Peverill et al. 1999). Ou Reang Ov soils at Sites 14 and 11 had adequate extractable S levels, by contrast with the low levels at Site 17. Those on Labansiek were generally adequate for plant growth even before S fertilizer addition.

Extractable Zn was adequate on all soils, but sub-soil levels < 0.6 mg/kg were found in Kompong Siem soils. Kompong Siem soils also had the lowest extractable B levels, with 15-30 cm again having the lower values. However, even on Ou Reang Ov soils extractable B levels were generally less than or equal to 0.3 mg/kg.

Emergence

In the EWS 2004, the trial at site 18 completely failed due to drought but other trials produced harvestable yield of at least some crops (Tables 3, 6). Peanut was the most successful crop, especially when grown in the MWS with emergence in 88 % of sowings. Peanut emergence was consistently high across soils in the EWS, apart from the lower values on Kompong Siem in 2004. In the MWS, emergence was generally decreased in peanut but still sufficient to establish adequate plant density. Two thirds of maize sowings emerged in both seasons. Only 25-38 % of soybean and mungbean crops emerged from EWS sowings, but 78 % emerged in the MWS (Table 3). For soybean and mungbean, a lower proportion of sown crops emerged in the 2005 EWS than in 2004. Overall, sesame was the least successful crop with no establishment when grown in the EWS and only one harvested crop out of nine sown in the MWS (Table 3).

Maize crop failed to emerge on each soil type, but the level of failures was most prevalent on Labansiek. Considering all soils, emergence was most reliable on Kompong Siem and least so on Labansiek. Emergence at Site 15 in the MWS 2005 failed completely except for peanut. Failure of emergence occurred on Ou Reang Ov and Labansiek soils in the MWS especially in 2005, but not on Kompong Siem.

Plant density

Plant density was relatively uniform at about 30 plants/m^2 for peanut at sites where emergence occurred (Table 4). Maize density was relatively uniform on Kompong Siem and Labansiek soils at 6-10 plants/m^2, but varied considerably from site to site and with season on Ou Reang Ov soil. Soybean density in the MWS was relatively uniform but decreased by 10-30 % on Ou Reang Ov soil at Site 17. In the EWS only 2 out of 8 sowings of soybean had successful emergence and of these the density of plants at Site 14 (Ou Reang Ov soil) was very low. Mungbean densities responded to soil type and season in much the same way as soybean.

Nodulation

At sites where legumes emerged and established successfully, plants were generally nodulated. Nodulation of the legumes was most reliable and satisfactory on Kompong Siem soils. Only one mungbean and one soybean crop, both on Ou Reang Ov soils, failed to form nodules. On Ou Reang Ov soil, nodulation varied from poor to adequate depending on site and season.

Table 4. Number of plants per square meter counted at 2-3 weeks after sowing of crops in the early (EWS) and main wet seasons (MWS). Values are means of four replicates

Sites	Soil group	Maize		Mungbean		Soybean		Peanut		Sesame	
		2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
					EWS						
13	Kompong Siem	6	-[A]	24	25	27	-[A]	29	32	-	-
17	Ou Reang Ov	-	5	-	-	-	-	-	33	-	-
14	Ou Reang Ov	6	2	14	-	4	-	18	32	-	-
15	Labansiek	8	-	-	-	-	-	-	30	-	-
LSD (p<0.05)		*1.4*	*1.2*	*1.8*	*5*	*3.3*	*1.5*	*4.5*	*1.3*		-
					MWS						
13	Kompong Siem	5	10	31	32	31	31	33	26	-	-
11	Ou Reang Ov	8	7	28	22	30	31	32	33	-	-
17	Ou Reang Ov	4	-	20	18	21	27	29	31	-	-
15	Labansiek	-	-	-	-	-	-	-	25	-	3
16	Labansiek	9	-	33	-	33	-	32	-	-	-
LSD (p<0.05)		*10.5*	*0.7*	*3.4*	*4*	*0.8*	*3.0*	*1.6*	*4.3*	-	*2.2*

[A] Crop failed to emerge or survive until maturity.

Table 5. Nodulation of legumes in the early wet and main wet seasons of 2004 and 2005. In 2004, nodulation was rated on a 0-10 scale (0- no nodules; 10 was the best) whereas in 2005, values represent number of nodules per plant

Sites	Soil group	Mungbean		Soybean		Peanut	
		2004	2005	2004	2005	2004	2005
EWS							
13	Kompong Siem	6.6	18	6.3	-[A]	5	21
14	Ou Reang Ov	5.4	-	7.1	-	6	9
17	Ou Reang Ov	-	-	-	-	-	12
15	Labansiek	-	-	-	-	-	7
LSD (p<0.05)		*1.9*	*3.0*	*1.4*	*1.3*	*1.8*	*7.3*
MWS							
13	Kompong Siem	8.1	9	9.0	12	8	35
11	Ou Reang Ov	7.4	4	8.0	0	7	46
17	Ou Reang Ov	3.9	0	4.0	2	3	14
15	Labansiek	-	-	-	-	-	25
16	Labansiek	8.1	-	8.0	-	9	-
LSD (p<0.05)		*1.0*	*6.0*	*1.1*	*3.3*	*1.4*	*12.6*

On Labansiek soil nodulation was satisfactory except for Site 15 in the EWS where poor nodule formation of peanut was obtained. However, few mungbean and soybean crops established successfully on Labansiek soil.

Crop yields

Peanut produced 0-3.4 t of pods/ha (Table 6). Consistently high yields were obtained on Kompong Siem soil, although the levels were about 0.6 t/ha higher in the EWS than the MWS. On Ou Reang Ov and Labansiek soils, large variations were obtaining in yield among sites and seasons. Of the crops that produced a harvestable pod yield, the minimum level was 1 t/ha on Ou Reang Ov soil in the MWS, but 6 out 14 peanut crops had 1.5 t of pods/ha or less.

Maize yields varied substantially with seasons and years so that they ranged from 0 to 4.5 t/ha (Table 6). Highest yields were obtained on Labansiek and Kompong Siem soils, but not consistently so. In general, yields in 2004 were higher than 2005, in both seasons. Soybean only produced yield in 25 % of EWS crops, but the two crops that produced seed had < 0.4 t/ha.

Table 6. Grain yield (t/ha) of field crops in on-farm trials (pod yield for peanut and seed yield for other species) in early wet (EWS) and main wet (MWS) seasons. Values are means of four replicates

Sites	Soil group	Maize		Mungbean		Soybean		Peanut		Sesame	
		2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
EWS											
13	Kompong Siem	1.75	-[A]	0.06	0.92	0.09	-	2.75	3.37	0	-
17	Ou Reang Ov	-	0.44	-	-	-	-	-	1.19	-	-
14	Ou Reang Ov	3.00	0.89	1.32	-	0.36	-	1.50	2.73	0	-
15	Labansiek	4.50	-	0	-	0	-	0	1.49	0	-
	LSD (p<0.05)	*0.94*	*0.35*	*0.28*	*0.38*	*0.16*	0.27	*0.86*	*0.48*	*0.10*	-
MWS											
13	Kompong Siem	4.09	2.09	1.53	0.90	3.32	1.46	2.09	2.73	0	0
11	Ou Reang Ov	2.64	1.78	0.81	0.72	0.89	1.24	1.60	2.98	0	0
17	Ou Reang Ov	1.07	-	0.51	0.24	1.91	0.30	1.36	1.03	0	-
15	Labansiek		-	-	-	-	-	-	1.15	-	0.07
16	Labansiek	4.29	-	0.42	-	2.19	-	2.02	-	0	-
	LSD (p<0.05)	*0.25*	*0.39*	*0.17*	*0.22*	*0.30*	*0.24*	*0.21*	*0.21*	*0.09*	0.09

Main wet season yield of soybean was up to 3.3 t/ha on Kompong Siem soil in 2004. Mungbean produced yields up to 1.3 t/ha in the EWS and 1.5 t/ha in MWS, but most crops had less than 1 t/ha.

In general, yields on Ou Reang Ov were lower than the other soils in the MWS, and prone to large variations with site and year of sowing.

Discussion

Peanut was the most reliable crop grown in both EWS and MWS. It failed to produce harvestable yield in 4 out 18 sowings, only one of which was in the MWS. While most crops of peanut produced < 1.5 t pods/ha, yields > 2.5 t/ha were obtained in 5 out 18 sowings with a highest overall yield of 3.4 t/ha. Peanut appeared to establish more reliably than other crops tested. This may be attributed to its drought tolerance once established, and also to the deeper sowing which may have ensured greater access to soil water availability for reliable germination and emergence. The large vigorous seed of peanut may thus reduce risk of poor establishment compared to other crops for sowing in the EWS. The extent to which more reliable emergence of other crops could be achieved by deeper sowing may warrant examination. Deeper sowing may come at the cost of increased loss of soil water due to more extensive tillage. If deeper sowing does not improve establishment of other crops, mulching, stubble retention or minimum tillage systems may conserve more water in the seed bed and hence enhance germination seed and success (Som Bunna et al. 2011).

Soil constraints

Crop management including the rates of fertilizers applied was designed to ensure that growth of cropped plants in the present study was limited only by rainfall and non-nutritional soil constraints. However, there were still occurrences of N deficiency symptoms during crop growth at Site 14 on the Ou Reang Ov soil in 2005. The fertilizer rates applied were modified from Dierolf et al. (2001), based on experience elsewhere but have not been validated by prior research in Cambodia. Further refinement in the fertilizer rates and/or time of application is required to avoid nutrient disorders especially of those elements prone to leaching, especially of N, K, S (Fox et al. 1985). Nitrogen deficiency in non-legume crops appeared to be widespread in all soil types suggesting that either greater rates are required or a different splitting of applications is needed to minimize N losses before crop uptake occurs (Sittiphanit et al. 2009). In preliminary DSSAT modeling of maize yield on Kompong Siem soils, N stress developed at 28-60 days despite the application of 115 kg N/ha (Wendy Vance, personal communication).

Soil analysis suggests that fertilizer will be necessary to achieve high yields on the three basaltic soils, although the nutrients required vary among soils. Kompong Siem soils have low extractable P, K, S and B and these nutrients may limit crop growth when fertilizer is not used (Peverill et al. 1999). By contrast, Ou Reang Ov soils had such high levels of extractable P, that it is unlikely that P fertilizer is needed for crops on this soil apart from a small starter rate to promote early root growth. Generally K and S levels on Ou Reang Ov soils appeared to be sufficient for crop growth (Peverill et al. 1999), but on the more oxidized, shallow profile forms, as represented by Site 17, deficiencies of both elements may occur and require appropriate fertiliser added. Boron levels were also marginal, and may be deficient for B-sensitive crops like mungbean and peanut (Bell 1999). However, no confirmation of B responses has yet been reported for these soils in Cambodia.

Labansiek soils were the most acid of those studied. Analysis of other profiles of Labansiek soils by Hin et al. (2006) suggested they can be more severely acid than found at the 2004 trial sites. Soil pH reported by Hin et al. (2005) was strongly acidic (pH $CaCl_2$ 4.2-5.5) in Labansiek. Indeed Site 15 for 2005 was more acid than the other sites in 2004 and 2005 and severe failure of crop growth occurred at this site for all species except peanut. Acute Mn toxicity symptoms were observed in soybean, mungbean and peanut. These results suggest that soil acidity was a factor responsible for the poor growth and yield of crops on the Labansiek soils. While lime may be an effective treatment for topsoil acidity (Fox et al. 1985), a ready supply of lime has not yet been developed in Cambodia. Moreover, lime may not be effective in ameliorating sub-soil acidity. For sub-soil acidity constraints, the most practical solution may be to select crop species and cultivars that tolerate acidity. Peanut is an obvious choice of acid tolerant legume crop, while cassava is a highly tolerant crop also (Dierolf et al. 2001).

Maize, mungbean, and soybean crops are quite sensitive to soil acidity (Dierolf et al. 2001). Their growth and yield can be depressed when Al saturation in the soil exceeds 40 %, but peanut can tolerate up to 70 % Al saturation (Dierolf et al. 2001). No pH amendments were used in this study. However, in the recent pot experiments conducted at CARDI, on Labansiek soil, when soil was limed at 3.52 g $CaCO_3$/kg to increase soil pH to about 6.0 (Seng 2000; Seng et al. 2006, the symptoms of Mn toxicity disappeared, and mungbean growth improved markedly. For maize, mungbean and soybean, a programme of selection for acid tolerance traits may be needed if these species are to play a significant future role in crop production on the acid basaltic soils.

While all legumes nodulated without inoculation on most sites there were notable cases of failure on Ou Reang Ov soil by mungbean and soybean. The cause is not clear since this soil was not the most acid and both species did nodulate on the Ou Reang Ov soil on other occasions. The fact that Ou Reang Ov soils tended to have highest mineral N at sowing may have suppressed early nodulation but is not likely to cause total nodulation failure. The failure of nodulation may have been more prevalent in mungbean and soybean had more of those crops emerged and successfully established. Indeed failure of nodulation cannot be ruled out as a factor in crop failure of mungbean and soybean. Peanut nodule numbers were also low on Ou Reang Ov soil in some cases. However, it is noteworthy that the poorest nodulation of peanut was on the very acid Lanabansiek soil with the highest extractable levels of NO_3-N and NH_4-N at Site 15 in 2005.

Apart from mineral nutrition, other soil factors such as physical properties and high soil temperatures may control the growth and yield of crops (Sys et al. 1993). High temperature may be a factor in the poor establishment of EWS crops. No soil temperature data was recorded during planting but at harvest in 2005, early afternoon surface soil temperatures were recorded as high as 38 °C. Mulching and stubble retention practices may be important in alleviating high temperature stress for seed germination and crop establishment in the EWS, especially for the early sowings. Ou Reang Ov soil is prone to crusting and hardsetting at the surface (Hin et al. 2006; Bell et al. 2006; Bell et al. 2007). High soil strength limits root penetration for adsorption of moisture and nutrients available in a deeper profile. No specific evidence of high soil strength was obtained from the experiment, but root profile investigations at the end of the experiment on Ou Reang Ov Soil showed a very poor and shallow root growth, generally <30 cm deep. Subsequent investigations on bulk density indicated that values declined with depth from 1.67 to 1.50 g/cm^3 in Kompong Siem (site 13) soil, increased with depth in Ou Reang Ov (site 11) from 1.41 to 1.77 g/cm^3 and were uniformly low (1.1 g/cm^3) in Labansiek soil.

Soil moisture regimes appear to be limiting factors in most soils. Kompong Siem and Labansiek soils used in the experiment had clay and clay loam textures to varying depth. In Thailand, red basaltic soils typically contain low available soil water content (Tawornpruek et al. 2005). This is offset by their depth if roots are able to exploit sub-soil moisture. Aluminium toxicity may limit root exploration into the sub-soil and hence limit crop production by making acid sensitive crops drought-prone. By contrast, acid tolerant species with deep roots such as rubber can have high productivity on Labansiek soils. In Kompong Siem, the available water content is high, but the limitation to root growth on this soil is the common episodes of waterlogging that may cause root pruning.

Seasonal rainfall and growing conditions

Crop performance was generally better in the MWS when rainfall is greater and more reliable than in the EWS. The only exception was peanut where yields were either similar to or lower than in the MWS than EWS. On the Kompong Siem soils, MWS yield of peanut was depressed by 0.5 t/ha. Peanut is not as waterlogging tolerant as soybean and maize, and hence tentatively the better yield of peanut on the Kompong Siem soil in the EWS may be attributed to less waterlogging. Soybean was most severely affected by the EWS conditions with few crops emerging and surviving to produce yield. The maximum yield of soybean obtained, 0.36 t/ha, was too low to justify planting this crop. Sesame failed to emerge or survive in 17 out 18 trials, with no effect of season in its lack of success.

The optimum growing season rainfall ranges for crops used in the experiment are reported as being: mungbean 750-875 mm, maize 500-1200 mm, soybean 500-1100 mm, peanut 400-1100 mm, and sesame 350-800 (Sys et al. 1993). In 2004 amounts of rainfall were generally sufficient for peanut, sesame and maize, but not for mungbean, and soybean. However, most sites experienced inadequate rainfall during the early vegetative stage which was reflected in failure of crops to establish completely at Site 18. In 2005, amounts of rainfalls during the growing season were generally inadequate especially for mungbean, maize and soybean.

Crops vary significantly in their temperature requirement for germination and growth. The optimum temperature ranges for crops used in the study are reported as being: maize 18-32 °C, mungbean 21-31 °C, peanut 18-30 °C, sesame 20-28 °C, and soybean 20-30 °C (Sys et al. 1993). Unfortunately, there was no temperature data recorded during the trials. However, in the EWS maximum day time temperatures in excess of 35 °C are common (Pheav et al. 2003). Hence high air temperature may be a factor in the poor establishment of EWS crops. The extent to which high air temperature has limited crop growth in the present study is unclear.

Soybean and mungbean varieties used in the experiment performed well in the main wet season but not in the early wet season. It was noted that most of the pods at Site 13 were empty and/or dropping from the plants in the early wet season. These crops at Site 13 only were sown in May and hence for the first 8 weeks of growth experienced maximum day lengths of the year. However, the mungbean and soybean sown nearby at site 14 at the same time did not experience the same problem with poor pod and seed set. Day lengths exceeding photoperiod requirements for seed set are not believed to the responsible for poor seed set in soybean DT84 (Andrew James *personal communication*). The poor pod and seed set at Site 13 were consistent with thrip damage.

Success and failure of trials in both seasons indicate that crops responded differently to time of sowing. Experiences from the 2004 and 2005 on-farm trials show that if crops are sown in late May, the success of establishment of sesame was 0%, followed by soybean (25%), mungbean (38%) maize (63%) and peanut (75%). If crops are sown in July-August, success for sesame was still only 20% across 10 sites, the success of mungbean, maize and soybean increased to 70%, whereas peanut had 80 % success in producing a harvestable yield. According to farmers' practice, sesame, mungbean, maize and peanut are to be sown between late March and early April when there had been a two or more significant rain events; and soybean in July (Chea et al., 2006). Our early wet season trials were sown in May (>20^{th}), 5-6 weeks later than farmers, resulting in many crops failing to yield especially sesame. A greater success was obtained in the main wet season, when crops were sown between mid July and August. In rainfed conditions where rainfall is not reliable, it would be useful to carry out supplementary irrigation at critical times such as the time of sowing to allow timely crop establishment and reduce the risk of failure. Supplementary irrigation may also increase stored soil moisture deeper in the soil profile for use during a period of succeeding drought assuming that no physical or chemical impediment to deep root growth exists.

Other factors

Variety selection for the crops used in the present study is still at an early stage in Cambodia. Hence it is possible that with improved varieties, better crop performance could be expected. Higher yield can also be pursued using varieties tolerant to specific soil and climatic conditions. In the case of the legume crops, it is not yet clear whether conditions were suitable for optimal nitrogen fixation.

Good quality seed produces healthy, vigorous plants and together with proper water and pest management will produce higher crop yield. While efforts were made to select good quality seed for the present experiment, poor quality seed may increase the risk of failure to emerge and establish. Hence under farmers' conditions the riskiness of the EWS crops may be greater than reported here.

Conclusions

From two years of on-farm experiments with contrasting rainfall (wet- 2004; dry-2005) to assess productivity of crops on basaltic soils in eastern Cambodia, we draw the following conclusions:

1. Peanut was most reliable in establishment and in producing harvestable yield in both EWS and MWS. It was productive on Kompong Siem soil producing yields comparable to its potential yield (2-3 t/ha). More work needs to be conducted to achieve higher yield on the well-drained Labansiek soils possibly be treating soil acidity (Al saturation and Ca supply). Overall peanut have widest adaption to soils and seasons. Peanut was the most reliable of the crops based on present crop management technologies.
2. Maize and mungbean grew on all soil types, but they produced yields only 35-40% of the potential yield levels (6-9 t/ha for maize, 2-3 t/ha for mungbean). More efforts are needed to achieve the potential yield including improved soil nutrient and acidity management, cultivar suitable for soil and climatic conditions, and better water and pest management.
3. Soybean was fairly suitable on Kompong Siem soils producing yields of 66-81 % of the potential yield (1.5-2.5 t/ha). More work is needed to achieve higher yield on the well-drained Labansiek soils due to soil acidity (Al saturation, P supply). Yield of soybean overall was poor in the EWS, which is consistent with farmers' reluctance to sow it before July, and its reputation for being more drought sensitive than the other crops grown.
4. Sesame when sown in mid- to late-May or in July was not promising on any of the soil types. Factors such as time of sowing, seed quality, water availability, insects and weeds, and fertilizer application techniques must be carefully considered if sesame is to be grown on any of the studied soils.
5. High yields of all crops except sesame were achievable but yields were variable among soils, sites and season. Overcoming the unreliable performance of crops is the key to decreasing the risk associated with non-rice crop production.

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