1. General Introduction

1.1. Upland farming systems in Southeast Asia

1.1.1. Traditional cropping systems

Traditionally agricultural systems in Southeast Asia's upland regions have been dominated by swidden agriculture (Rerkasem et al., 2009), which involves shifting cultivation and a long period of fallow in between crops. This means the farmers grow the same crop species every year but in different fields. They rotate the fields sown each year so every field has a long period of fallow (5-7 years) to recover whilst other fields are cropped (Bruun et al., 2009). When there is a change from swidden agriculture to continuous annual cropping, the loss of topsoil soil organic carbon (SOC) is between 13 to 40% (Detwiler, 1986; Davidson and Ackerman, 1993; Palm et al., 2005). The long fallow period in swidden farming enables recycling of nutrients and organic matter for the next crop, which was traditionally sown without cultivation (Bruun et al., 2009). Significant changes in land use in Southeast Asia over the last 50 years (Narintarangkul Na Ayuthaya, 1996; Rerkasem et al., 2009; Patarasuk and Fik, 2013) has seen competition for arable land intensify, and consequently less swidden farming systems remain (Bruun et al., 2009).

1.1.2. Modern farming systems approach

Sustainable intensification of agricultural systems occurs when productivity is increased on the same area of land without adverse effects on the environment and human health (Baulcombe et al., 2009). Sustainable intensification involves more efficient use of existing natural resources and a shift to production technologies that reduce the impact of agricultural activities on the environment and the natural resource base (Pretty and Bharucha, 2014). Examples of these shifts includes the conversion from ploughing to no-tillage, from the use of fertiliser to nitrogen fixing legumes, and the change from reliance on only chemical insecticide options to integrated pest management (Pretty and Bharucha, 2014).

Conservation agriculture is an element of sustainable intensification which is a method of farming whereby minimal soil disturbance occurs (Kassam et al., 2009). Soil is not ploughed, and all crop residues are retained *in situ* above and below ground to be recycled as organic matter and nutrients (Kassam et al., 2009). Crop diversity is important in this system, with crop sequences including legumes or alternative crop species encouraged (Kassam et al., 2009; Pretty and Bharucha, 2014).

Conservation agriculture originated in North America, as part of a strategy to mitigate extensive soil erosion in the US Midwest in the 1930s (Pretty and Bharucha, 2014). The primary reasons for adoption of conservation agriculture are machinery, fuel and labour savings, increases and stabilisation in yields, reduced soil erosion, and improved nutrient and water use efficiency (Centero-Martinez et al., 2007). Additional benefits include increased organic matter and soil C sequestration over time, improved soil structure and soil health and ultimately a sustainable agricultural system (Kassam et al., 2010; Pretty and Bharucha, 2014).

Approximately 5.3 million hectares per annum of conservation agriculture has been adopted globally since 1990 (Kassam et al., 2009) and estimates for 2010 place conservation agriculture (encompassing a broad range of agricultural systems globally) at 17 million hectares (Kassam et al., 2010). Of this, Asia comprises only

2.3% or 2.6 million hectares, with the majority in Kazakhstan (Kassam et al., 2009). Where adoption has occurred in Asia, benefits have been evident. For example, conversion to conservation agriculture enabled farmers in Korea to grow two crops in one year. Similarly, in the Indo-Gangetic Plains no till wheat is being grown after rice (Kassam et al., 2009). These examples suggest further implementation within Asia may be possible.

1.2. Cambodian upland farming systems

1.2.1. Upland cropping

The focus region for this thesis is Northwest Cambodia, which is a major centre for upland crop production in the country. The study region encompasses the Districts of Sala Krau and Pailin, in Pailin Province and Samlout District in neighbouring Battambang Province (Figure 1.1). Prior to 1998, during more than two decades of war, the area consisted of thick tropical primary forest (Touch et al., 2013). Land clearing for agricultural production, mainly by displaced persons, accelerated once peace was instigated, despite the Northwest region still being the most heavily landmined area in Cambodia (The HALO Trust, 2016). The advent of upland cropping in the Northwest saw a range of crops produced which included maize and soybean as the primary crops and minor crops such as mungbean, peanut and sesame (Provincial Department of Agriculture, 2015a). Soil fertility of recently cleared rainforest was high and maize was very profitable, which resulted in the domination of continuous maize in the farming system and a subsequent decline in crop diversity (Brown and Johnstone, 2012). Cassava has emerged as a new crop for the region over the last 10 years, due to reduced profits from maize and a strong market demand from Thailand (FAOSTAT, 2015; Martin et al., 2015a), and by 2015 97% of the Pailin Province arable uplands were sown to cassava (Provincial Department of Agriculture, 2016).

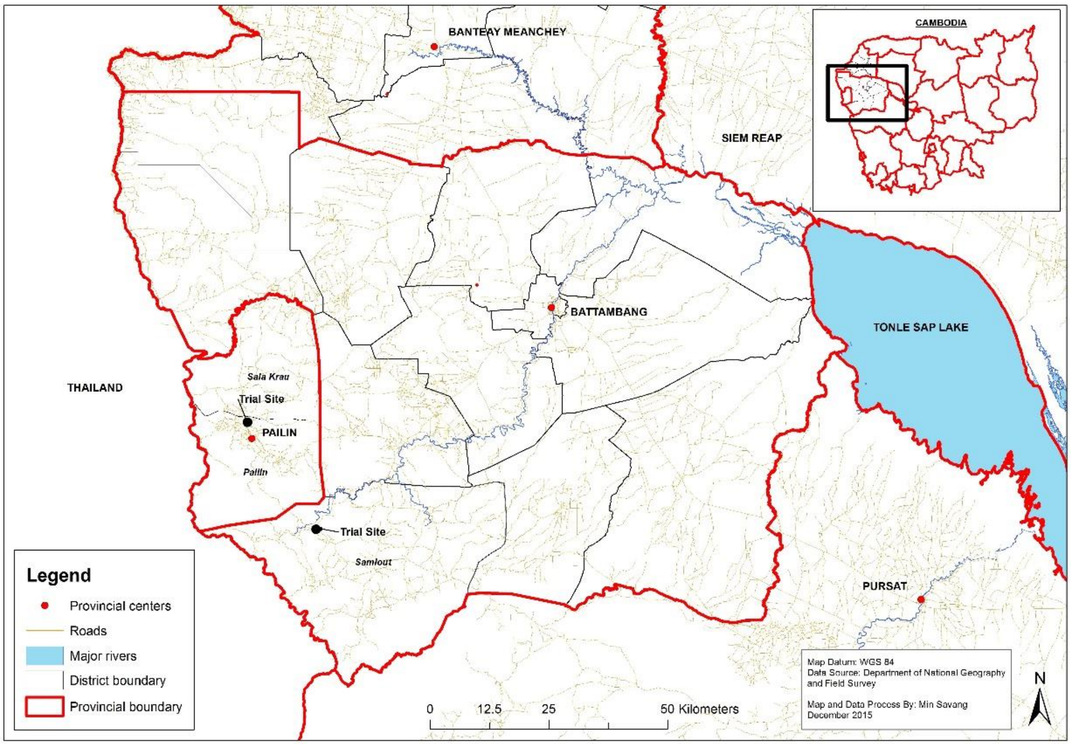

Figure 1-1 Map of Cambodia with the location of the focus region and experimental sites in Pailin District, Pailin Province and Samlout District, Battambang Province.

1.2.2. Climate and Topography

Long term rainfall records are patchy due to the extended period of war in the region from the 1970s through to 1998. The most complete records are for Battambang City, and data described in this chapter are from 1981 to 2015. In our focus regions, rainfall recording recommenced in Pailin City, Pailin Province in 2002 and began in Kantout Village, Samlout District, Battambang Province in 2006. All sites are within a 95 km radius of Battambang City, yet even across a relatively small area that is classed as having the same climate, there are large differences in seasonal rainfall. The average annual rainfall for Battambang city is 1294 mm while at Pailin it is 1194 mm. However, more rain is received at Samlout with an average of 2003 mm per annum, the majority of which falls from April to October, when Samlout may receive between 50 to 200 mm more rainfall per month than the other sites (Figure 1.2). This needs to be accounted for when making farming related decisions, and is currently not considered by farmers when making cropping decisions.

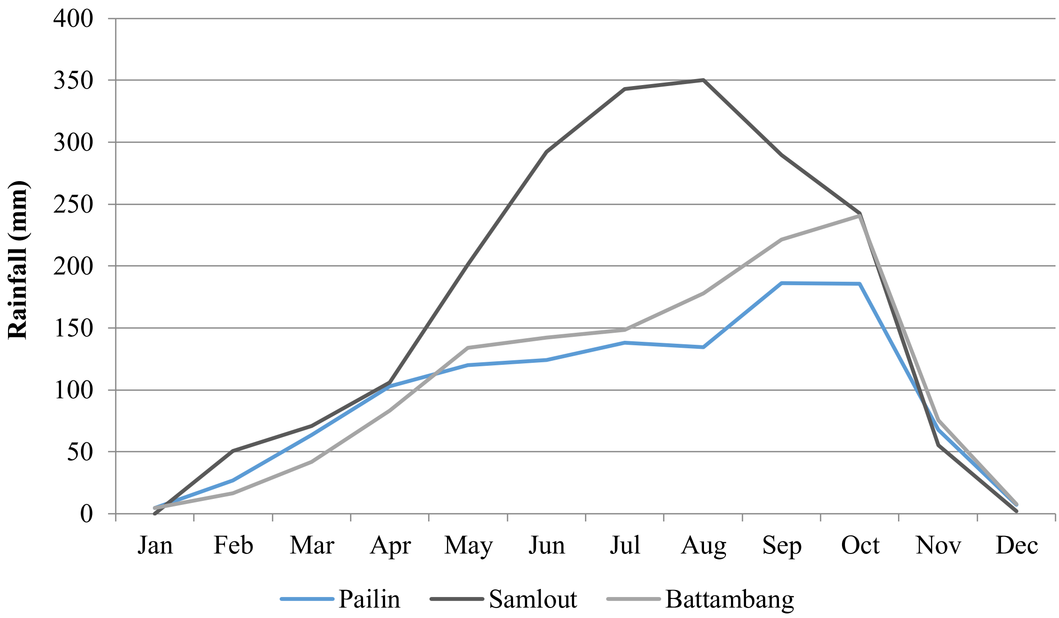

Figure 1-2 Average rainfall for the locations of Pailin City, Samlout District and Battambang City in Northwest Cambodia. Source: Pailin: (Provincial Department of Agriculture, 2015c), Samlout: (MJP, 2015), Battambang: (Provincial Department of Agriculture, 2015b).

Northwest Cambodia has a monsoonal climate referred to in this work as having three distinct seasons. The pre-monsoonal period is from March to June, the monsoon season is from July to October and the post-monsoonal period is from November to February (Montgomery et al., 2016c). The average annual temperature at Battambang is 28°C (Table 1.1). The pre-monsoon season is the hottest with an average maximum temperature of 35°C, and the post-monsoon season is the coolest with an average minimum temperature of 21°C. Average relative humidity at Battambang is 80% with a range from 62% to 95% throughout the year.

Table 1-1 Summary of climate data for Battambang City, Pailin City, and Kantout Village, Samlout District, Northwest Cambodia

Site	Variable	Pre-monsoon Mar-June	Monsoon July-Oct	Post-monsoon Nov-Feb	Annual Total
Battambang	Mean rainfall (mm)	401	788	105	1294
	Mean temperature (°C)	30	28.1	26	28
	Mean daily maximum (°C)	35	32	31	32.8
	Mean daily minimum (°C)	25	24	21	23
	Temperature range (°C)	22-39	22-35	17-37	17-39
	Mean relative humidity (%)	77	85	78	80
	Relative humidity range (%)	62-93	73-95	64-90	62-95
Pailin≠	Mean rainfall (mm)	268	719	101	1088
	Mean temperature (°C)	30	28	25	28
	Temperature range (°C)	21-45	21-45	13-40	13-45
	Mean relative humidity (%)	70	76	70	72
	Relative humidity range (%)	27-97	40-98	25-97	25-98
Samlout†	Mean rainfall (mm)	495	1211	139	1845
	Mean temperature (°C)	29	27	24	27
	Temperature range (°C)	21-46	20-48	8-37	8-48
	Mean relative humidity (%)	77	84	74	78
	Relative humidity range (%)	31-99	36-98	27-99	27-99

Battambang: Veal Bek Chan Meteorology Station, Battambang City. Years recorded 1981-2015 (Provincial Department of Agriculture, 2015b)

†Temperature data for Samlout is for two time periods: June 2013 to May 2014 and January 2015 to May 2015

†Rainfall data for Samlout is for the period from June 2013 to June 2015

≠ Temperature and rainfall data for Pailin is for the period from June 2013 to May 2015

1.2.3. Soils

The main upland crop soils in Northwest Cambodia are known locally as Labanseak (Dermasol) and Kampong Siem (Vertosol) (White, 1997). The Labanseak are red friable clay-loams and the Kampong Siem soils are black self-mulching clays. Table 1.2 summarises soil surveys conducted in upland fields across a range of soil types throughout Samlout District, Battambang Province, and Pailin Province. The samples from these surveys had an average pH_{H2O} of 6.4 (6.1 – 6.6). Values below pH 6 were not evident, which is in contrast to other results available for upland soils in this region (Chan et al., 2009). A neighbouring District to Samlout, Rotanak Mondul District, had an average pH_{H2O} of 5.5 (5.0 - 6.0) (Chan et al., 2009), possibly reflecting the older age of cultivation of the fields in that District. However, mean OC concentrations were the same from both surveys at 2.3%. Mean total nitrogen (N) concentrations were similar in both surveys, with 0.21% for Samlout-Pailin and 0.18% for Rotanak Mondul. Phosphorus (P) concentrations (Olsen P) in Meanchey Commune and Pailin stand out as being very low compared to the other village sites analysed (Table 1.2) and are supported by visual evidence in these fields of P deficiency in maize crops.

Table 1-2 Soil chemistry characteristics of upland soils in Samlout District, Battambang Province and at our research site in Pailin Province. Source: ASEM2010/049 soil survey (CARDI, 2013)

District	Commune	Site No.	pH $_{H2O}$	EC $_{H2O\ 1:5}$	OC	OM	Total N	Olsen P	Exch .K+	Exch .Na+	Exch .Ca+	Exch. Mg+
			1:5	µS/cm	%	%	%	mg/Kg	cmol/Kg			
	Meanchey	17	6.6	151	1.93	3.3	0.16	6.4	0.7	0.2	13.0	5.6
Samlout	Samlout	98	6.4	377	2.4	4.2	0.21	53.6	1.3	0.3	9.9	4.3
	Sung	10	6.3	113	2.3	4.0	0.31	51.7	0.6	0.6	8.3	5.1
Pailin	Pailin$^{\beta}$	1	6.7	200	1.8	3.1	0.17	7.1	1.1	0.2	23.2	8.6
	Mean		6.4	311	2.3	4.0	0.21	42.5	1.1	0.3	11.7	5.0

$^{\beta}$Data is for the research study site at Pailin with 16 samples taken across the site prior to commencing research trials reported in Chapters 3 and 5.

Soils in the upland regions of Pailin and Battambang have not yet been extensively described, as farming has only recently expanded into these regions (Sarith et al., 2006). The other major factor in limited soil characterisation is that the risk of triggering an anti-tank mine is too high to safely undertake soil profile descriptions or subsoil sampling (MJP, 2014). Subsequently, it is not possible to determine the water holding capacity of soils below the surface layer which is an added constraint to conducting soils and farming systems research in Northwest Cambodia.

1.2.4. Cropping practices

Land use changed directly from primary forest cover into annual cash crop farming in Northwest Cambodia. In contrast to neighbouring countries and also Provinces in

Northeast Cambodia, the region did not adopt swidden agriculture principles (Nesbitt, 1997). Mechanical tillage dominates the upland system and fields are usually ploughed twice prior to sowing (Brown and Johnstone, 2012). This is one of the largest operational costs in the cropping gross margin. Current practice in upland areas involves growing two crops per year, with a pre-monsoon season crop (February-June), followed by a monsoon season crop (July-October) (Figure 1.3). Land is ploughed in between crops. Following the monsoon season crop land is ploughed or left fallow from November to February (Martin et al., 2015a).

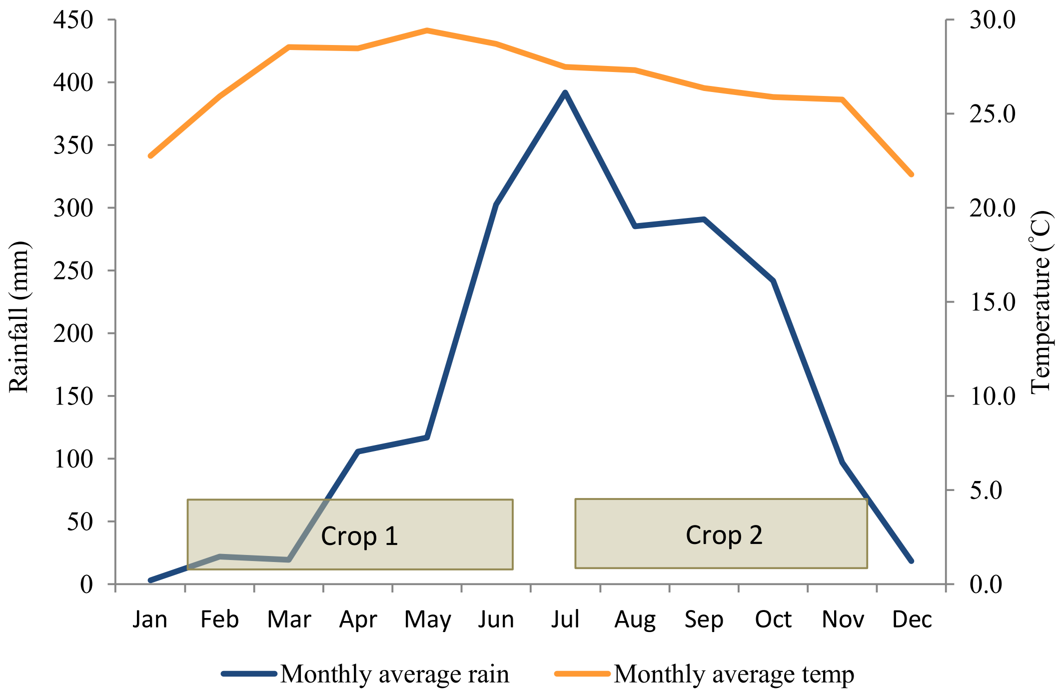

Figure 1-3 Crop production windows and monthly average rainfall and temperature for upland areas in Northwest Cambodia.

Soil water content is not considered in planting decisions. Fallow management is not practised, resulting in high weed burdens and depleted soil moisture (Belfield et al., 2013). The pre-monsoon crop is sown at the hottest time of the year and due to lack of fallow management, there is minimal subsoil moisture to support crop growth. The monsoon crop grows during the wettest period of the year and reaches physiological maturity in early to mid-October, at which time water use ceases and the crop begins to dry down until harvest. The residual soil moisture remaining from the October rainfall is potentially enough to fill the entire soil profile by harvest. This soil water could be stored and utilised to grow a crop in post-monsoon or the following pre-monsoon. However due to poor fallow management it is currently utilised by weeds and lost through soil evaporation after ploughing.

1.2.5. Crop diversity

The area sown to rotation crops such as legumes and sesame has declined rapidly over the last 10 years in the Provinces of Pailin and Battambang, in which the Districts of Sala Krau and Samlout are respectively situated. Previously, soybean was the major crop in both Provinces, consisting of greater than 40% of the production area in 2005, whilst the other crops grown included maize, mungbean and sesame (Provincial Department of Agriculture, 2015a; Provincial Department of Agriculture, 2016). Cassava was introduced to the region in 2006, since which time it has increased in area annually with the 2015 Provincial statistics reporting it represents 97% of the Pailin upland production area with the remainder sown to maize (2%) and mungbean (1%) (Figure 1.4.). Battambang Province cropping systems are more diverse than Pailin Province, however cassava now dominates the farming system there also (Figure 1.5). Statistics for Battambang Province in 2014 reported that 58% of the cropping area was planted to cassava, 23% to maize, 8% to soybean, and the remaining 11% was mungbean, peanut and sesame (Provincial Department of Agriculture, 2015a).

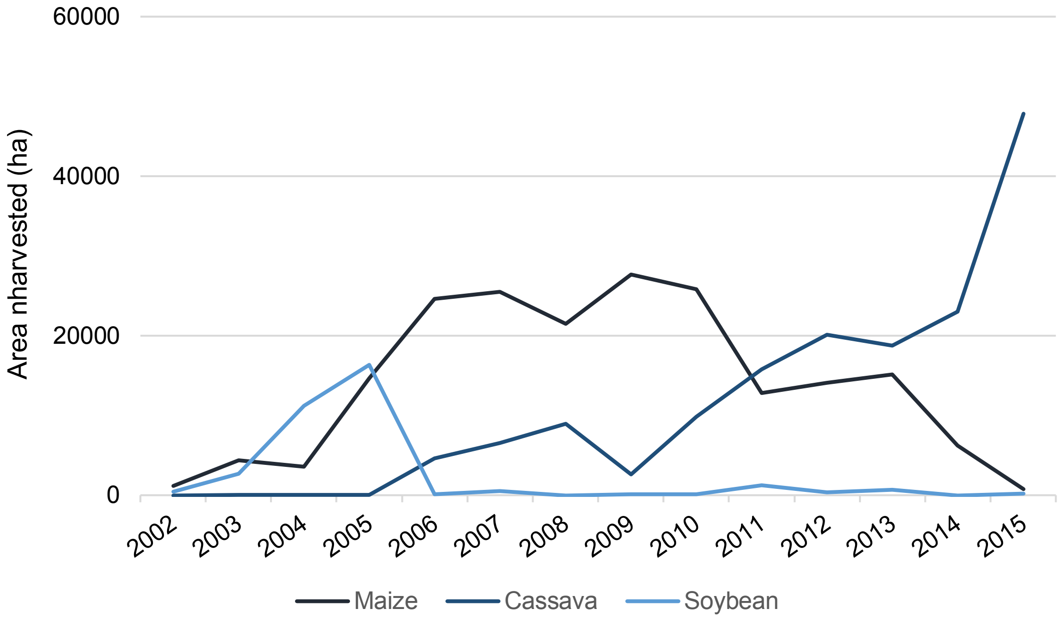

Figure 1-4 Fourteen year production trends in the area of maize, cassava and soybean in Pailin Province.
Data source: (Provincial Department of Agriculture, 2016) .

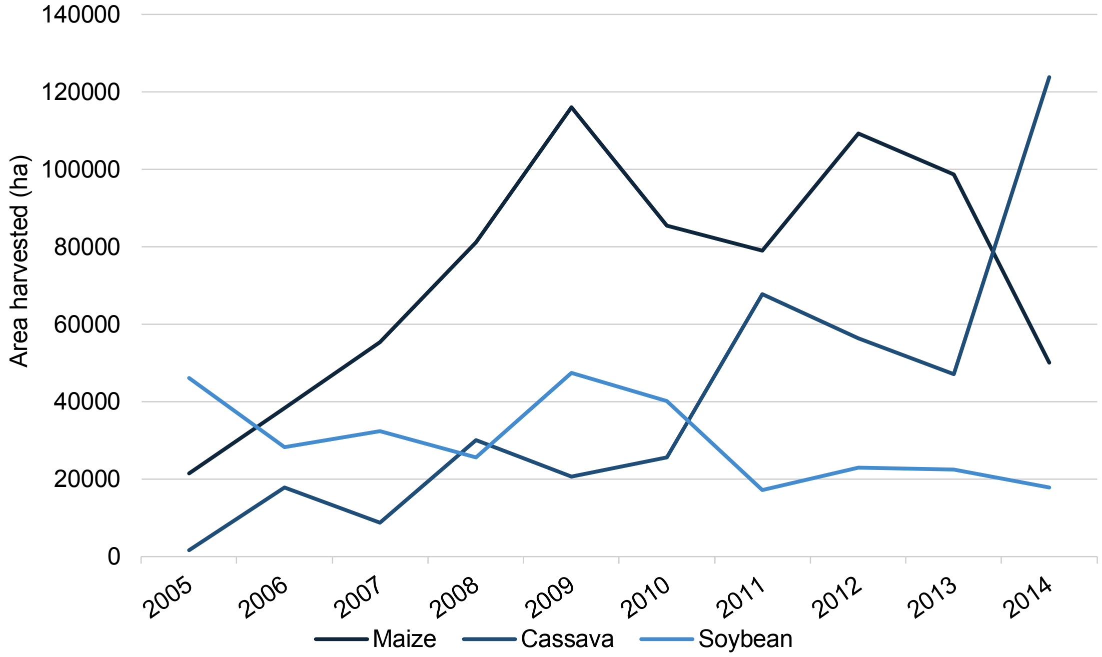

Figure 1-5 Ten year production trends in the area planted to maize, cassava and soybean in Battambang Province.
Data source: (Provincial Department of Agriculture, 2015a).

In cases where cash income has risen sufficiently farmers are planting areas to fruit trees and horticulture (Provincial Department of Agriculture, 2016). Perennial tree plantings appears to be a more sustainable option for this region than current farming practices involving extensive ploughing in undulating terrain and high rainfall zones.

Erosion is reduced under permanent tree plantings and continual ground cover crops (Nguyen et al., 2008). Land use change to more permanent fruit tree orchards would mirror that of neighbouring Thai province, Chantaburi, which is largely planted to tropical fruit trees (Lop, 2014).

1.2.6. Crop nutrition

Traditionally upland farmers in Northwest Cambodia do not use inorganic fertiliser, however this appears to have changed with an average of 55% of farmers surveyed in 2013 having applied fertiliser to their 2012 crop (Montgomery et al., 2016b). Farmers report that the main reason for applying fertiliser is due to their observations that maize yields have declined and the crops grow better with fertiliser (Montgomery et al., 2016b). Over a five year period the average maize yield has decreased from 4.1 t/ha in 2006 to 3.4 t/ha in 2010 ((National Institute of Statistics, 2009) (National Committee for Sub-National Democratic Development, 2012). Farming practices have not prioritised soil fertility with extensive continuous cropping of maize, and minor use of legume in the region, hence any N benefit to the whole farming system is insignificant (Brown and Johnstone, 2012). Farmers commonly burn crop residues (Chan et al., 2009) and plough in what residual remains (Montgomery et al., 2016b). This results in a high risk of soil erosion during monsoonal rainfall and consequently the cumulative effect of soil degradation is fast becoming apparent (Martin and Belfield, 2007; Martin, 2014).

1.2.7. Production constraints and farmer perceptions

Constraints to production commonly reported by upland farmers in Northwest Cambodia include droughts and heavy rains, insect pressure and cash flow shortages

(Montgomery et al., 2016b). Further to this, across both regions of Pailin and Samlout, approximately 20% of farmers experienced food shortages during the year, particularly in March and from August through to October (Brown and Johnstone, 2012). Samlout District is comprised of smallholder farmers of which the majority require assistance with 69% of households deemed as maintaining an average livelihood and 23% were still poor (Martin et al., 2012a). Pailin is a mixture of smallholder farmers and large family owned farms of which 57% of households were categorised as average and 27% were poor (Martin et al., 2012a).

There is a lack of income diversity for small-holder farmers in Northwest Cambodia who struggle to cover household expenses with crop income (Belfield et al., 2013). Cash flow shortages are most common during February to March and November to December (Montgomery et al., 2016b). It is envisaged that food and income security in our target region could be increased through implementation of conservation agriculture, as was found in Malawi where farmers who adopted conservation agriculture increased maize production by 50% and household food security was 36% higher than that of non-adopters (Nyambose and Jumbe, 2013). Similarly in Zimbabwe, farmers who adopted conservation agriculture transformed their households from requiring food aid packages due to food shortages, to five years later providing food aid to others (Wagstaff and Harty, 2010).

Furthermore, smallholders are not consuming the majority of their produce, and it appears that entrepreneurs are benefiting from the expansion of upland crops in the Northwest. The Pailin region now has 40 grain receival points, with a combined capacity for short term storage of over 112 000 tonnes of grain (Bunthoeun, Ly pers. comm.). The majority of maize is exported to Thailand with 79% of the national maize crop destined for export, 65% of which goes to Thailand and 35% to Vietnam (Martin et al., 2015a).

1.3. Environmental issues

1.3.1. Deforestation

Large tracts of rainforest have been cleared across Southeast Asia due to pressure from escalating populations, government policy, market demand and lowland soil degradation to expand the area of arable land (Valentin et al., 2008). Cambodia, including our focus region, has the additional factor of the "rosewood war" wherein forests are being illegally cleared to access highly valuable rosewood timber (Milne, 2015). Northwest Cambodia has seen rapid expansion of rainfed upland cropping as a result of land grants and extensive land clearing, since the end of the Khmer Rouge civil war in 1998 (Touk, 2004). Once the valuable timber has been removed, techniques employed in land clearing, have predominantly been the slash and burn method of clearing. This is followed by ploughing several times to create a seedbed. Clearing of sloping land that is subjected to tropical rainfall adds to the environmental hazard and accelerates soil loss and corresponding soil fertility decline (Meadows, 2003; Montgomery, 2007; Nguyen et al., 2008). Cambodia had the fourth highest deforestation rate in the world between 2000 and 2012, placing it behind Paraguay, Malaysia and Indonesia (Hansen et al., 2013).

1.3.2. Soil erosion and degradation

Developing countries account for up to 80% of global soil degradation (Lal, 2000). Replacement of nutrients that have either been exported in grain, burnt, or ploughed, or removed from the field for fodder or fuel, or washed away in soil erosion, is rarely considered or acted on (St. Clair and Lynch, 2010). Many farmers use the natural soil resource base without knowledge of potential negative consequences, which may be exacerbated by the disruption of traditional cropping practices from war, disease and migration (St. Clair and Lynch, 2010). However, in Northwest Cambodia the majority of land was cleared post conflict and most farmers are displaced citizens from lowland paddy areas with no knowledge of upland farming practices. In 1999 Pailin's population comprised of 77% recent arrivals from other provinces or countries (National Institute of Statistics, 1999). This dearth of upland farming knowledge appears pivotal to the landscape degradation and crop production issues the region is facing.

Land use change from forest to annual cropping systems generally results in a reduction in SOC by 20-40% during the first five years after conversion (Bruun et al., 2009). After such time the SOC concentration will stabilise depending on variables including farming practices, climate, soil type and initial carbon content (Detwiler, 1986; Davidson and Ackerman, 1993; Bruun et al., 2009). Land that has been cleared for upland farming in Northwest Cambodia is typically subjected to excessive cultivation and burning of crop residue. This has led to rapid soil fertility decline and soil erosion (Belfield et al., 2013). Cultivation of sloping land for annual crops increases the risk of soil erosion due to mechanical tillage with a progressive translocation of soil downslope exacerbated by gravity and crop choice (Dupin et al., 2009), which may eventuate in low fertility soil with low infiltration rates (Turkelboom et al., 1999).

Agricultural production is one of the main causes of soil erosion worldwide (Montgomery, 2007). In Southeast Asia nearly half of soil degradation is due to water erosion, with a further 24% due to chemical deterioration and 20% from wind erosion (Van Lynden and Oldeman, 1998). Crop choice can increase erosion risk, and cassava in particular has a slow initial growth rate and provides only 50% canopy cover at its peak biomass. This exposes soil to raindrop impact, and further to this, cultivation to harvest tubers increases the risk of erosion (Moench, 1991; Nguyen et al., 2008; Valentin et al., 2008). Additionally, half of the cassava fields in Pailin are planted up and down the slope, whereas in comparison only 3% of fields are planted this way in Kampong Cham Province (Wenjun et al., 2016). This greatly increases erosion risk. and the reason for using this planting method is unknown (Wenjun et al., 2016). Cassava production in Cambodia and Laos has doubled from 2009 to 2013, and there has been an increase in production of 7.5% per annum across Southeast Asia (FAOSTAT, 2015).

1.3.3. Landmine hazards

As a result of many years of conflict, Cambodia was left with an estimated four to six million land mines and several million unexploded ordnances (UXOs) in the soil (Gildestad in Gibson et al. (2007)), making it one of the most mine-affected countries in the world (Shimoyachi-Yuzawa, 2012). This thesis research is located within the most heavily landmined region in Cambodia, the Northwest border provinces (The HALO Trust, 2016) where mines are still being discovered on a regular basis. Demining teams are continuously working to clear land of anti-personnel, anti-tank mines and UXOs across these regions by priority listing (The HALO Trust, 2016). This atypical constraint hinders soil research as sampling at depth is too high a risk so only the surface soil characterisation (0-15 cm) is possible. However it does present a unique opportunity to promote adaptation of conservation agriculture in the farming system as an occupational health and safety measure for farmers.

1.4. Research aims and thesis framework

This research project is designed to test alternative practices to the current farming system in the study areas of Pailin and Samlout in Northwest Cambodia, where soil degradation is evident and crop yields are declining. On-farm research trials and a survey of farmers in the region will seek to identify constraints to production and options that will assist to improve the sustainability of the farming system and wider catchment.

This work begins with a quantitative review of current farming practices and perceptions summarised from a large farmer survey conducted in our focus Districts at the beginning of this study (Chapter Two). This information assists to explain the reasons behind some farming decisions, identify gaps in knowledge and research opportunities, and clarify the current picture of farming systems in Northwest Cambodia.

Small plot replicated field experiments evaluate crop sequences and whether it is possible to make more efficient use of rainfall throughout the whole year (Chapter Three). Currently the pre-monsoon crop often fails which is thought to be due to extreme temperatures and erratic rainfall during this growing season. After the monsoon crop is harvested, and there is significant residual water remaining in the soil that could possibly be used by another crop. This work examines whether the cropping intensity could be increased from two crops to three crops per annum to make better use of residual moisture and improve the profitability of Northwest Cambodian upland farming systems. Furthermore alternative crop sequences involving rotation crops are compared to continuous maize for sequence viability and profitability.

The subsequent study investigates the effect that a delay in sowing date by two months has on yield and gross margin returns for maize-based sequences in rotation with cowpea, mungbean, peanut, sunflower, sorghum or continuous maize (Chapter Four). The feasibility of introducing new crops into the agricultural system is assessed, based on yield, insect pressure, drought tolerance and their performance relative to traditional maize.

Further research trials investigate the effect that conservation agriculture had on the productivity of maize and sunflower (Chapter Five). Farmers frequently experience crop failure in the pre-monsoon season and currently crops are not grown during the post-monsoon season. It is thought the risk of growing either pre-monsoon or post-monsoon season crops would be reduced if tillage was eliminated and surface crop residues were retained *in situ* to conserve soil water and increase yield.

The conclusion of this thesis (Chapter Six) provides a summary of the research with key findings and their interactions, presented as a series of best management practice recommendations to encourage sustainable intensification of upland farming systems in Northwest Cambodia.

2. Farmer knowledge and perception of production constraints in Northwest Cambodia

This work contained in this paper is under review by the Journal of Rural Studies.

Montgomery, S.C., Martin, R.J., Guppy, C, Wright, G.C., Tighe, M. Farmer knowledge and perception of production constraints in Northwest Cambodia. Journal of Rural Studies. Under review.

3. Productivity and profitability of upland crop rotations in Northwest Cambodia

The work contained in this chapter has been accepted for publication by the Journal of Field Crop Research.

Montgomery, S.C., Martin, R.J., Guppy, C, Wright, G.C., Flavel, R.J., Phan, S., Im, S., Tighe, M. 2017. Productivity and profitability of upland crop rotations in Northwest Cambodia. *Journal of Field Crop Research. 203 150-162.* DOI: 10.1016/j.fcr.2016.12.010.

4. Crop choice and planting time for upland crops in Northwest Cambodia

The work contained in this chapter has been published in the Journal of Field Crops Research with the exception of lines 17-21 on page 106.

Montgomery, S.C., Martin, R.J., Guppy, C, Wright, G.C., Flavel, R.J., Phan, S., Im, S., Touch, V., Andersson, K.O., Tighe, M. Crop choice and planting time for upland crops in Northwest Cambodia. Journal of Field Crops Research. 198 290-302. 10.1016/j.fcr.2016.07.002.

5. Yield Responses of Maize and Sunflower to Mulch under No-Till Farming Conditions in Northwest Cambodia

The work contained in this chapter has been published in the Asian Journal of Crop Science.

Montgomery, S.C., Tighe, M., Guppy, C, Wright, G.C., Flavel, R.J., Phan, S., Im, S., Martin, R.J. 2016 Yield Responses of Maize and Sunflower to Mulch under No-Till Farming Conditions in Northwest Cambodia. Asian Journal of Crop Science. 8(2) 71-86.

6. General conclusion

This research illustrates how conservation agriculture in the upland regions of Cambodia can contribute towards environmentally sustainable farming systems through reduced tillage, better use of residual soil water, reduced soil and nutrient loss and consequently increased yields, profitability and less risky cropping opportunities. This study demonstrated how modifications to the current traditional farming system, such as a shift in crop sowing windows, change in crop sequencing and conversion to no tillage, can increase productivity and profitability. As the area of land per capita available for farming shrinks and demographic pressure swells, the importance of conservation agriculture will increase even further in regards to food security and maintenance of arable land (Lal, 1993). The major agricultural challenge ahead for this region is to be able to increase productivity in a sustainable way on both old and new lands, in order to feed the increasing population, which is growing at an estimated 1.75% per annum in Cambodia (Blair and Blair, 2014). This study is applicable to other developing regions in the tropics and sub-tropics across Southeast Asia, where similar issues of agroecological sustainability, food security and population demographics also exist.

The baseline survey of farmers I conducted in the focus regions of Pailin and Samlout reported that farmer's crop yields have decreased over a five year period and they believe their soil fertility is declining. The major constraints to production identified in the survey were drought, floods and cash flow shortages at certain times of the year. Findings from my overall research study provide direct evidence of effective measures to combat these major constraints through a change in management practices. This is provided as a series of agronomic recommendations that we have proven will reduce the risk of crop failure and increase sustainability of the farming system. It is the most comprehensive set of guidelines developed for Northwest Cambodia to date, due to the difficulties of conducting field research in this high risk environment. Adoption of these recommendations are expected to improve household security which may extend to health, education and employment.

This level of field research has not been previously conducted in the region and as such is new information for researchers and farmers from this emerging agricultural region. The dearth of agricultural field research in this upland region is due to several factors which stem from the fact this is a remote area that was involved in civil war until 1998. The area is the most heavily landmined region remaining in Cambodia and hence conducting field based experiments is challenging and not often undertaken. The results of on-farm research from this thesis provide extensive agronomic, soil and climate data for two sites, across a range of crops, sowing times and seasons, none of which had been previously evaluated in a field environment. Advanced statistical analysis using mixed linear models, generalised additive models and partitioning of variation, enabled us to account for variation encountered in field trials based in remote tropical conditions. This information will prove invaluable to proof the APSIM crop model which can now be validated against crop yield, climate and soil data under Cambodian conditions. For example, site data including surface soil moisture, rainfall, yield and agronomic data, were utilised to predict plant available water (PAW) down the soil profile to a depth of 1.4 m throughout the growing seasons (Chapter four). Without conducting field based research this useful prediction of PAW in relation to sowing time and season, would not have been possible. Due to the unknown risk of land mines at depth, we were unable to characterise the sub-soil, hence we developed this novel APSIM model adaptation in order to achieve this aim. This is a globally applicable tool in relation to land mine affected areas where sub-soil sampling for moisture and nutrients poses a high risk to research personnel.

6.1. Recommendations for improved management practices for upland farming systems

6.1.1. Conserving crop residues

This research has demonstrated that by conserving crop residues in the pre-monsoon and post-monsoon periods, yield was significantly increased for maize and there were increasing yield trends for sunflower at Pailin. However, the same yield response was not observed at Samlout, possibly as a result of confounding of residual soil water associated with higher rainfall at this site. This adds further support to the notion that with proper preservation of soil moisture, appropriate crop choice and time of sowing, a post-monsoon crop can be successfully grown solely on residual soil moisture. From this research we recommend that farmers implement no tillage farming systems, where crop residues are retained on the soil surface, not burnt or ploughed as per the traditional practice of the region. To highlight moisture differences, a pictorial approximation of the moisture loss from the two different farming methods is included (Figure 6.1). This illustrates that in the same soil there is more PAW if no till is practised, compared to disturbing and ploughing the soil which leads to significant moisture loss during each operation (Figure 6.1). Increased PAW for crops means a reduced risk of crop failure as the extra moisture available to the crop acts as a buffer zone to prevent terminal crop stress and may also equate to increased yield potential. Moisture is a critical factor in crop success/failure in the pre-monsoon and post-monsoon periods. This research outcome of retaining crop residues to aid moisture conservation is novel for the region and previously unquantified for Northwest Cambodia. My research provides important leverage to combat misconceptions embedded in this farming demographic where 27% of farmers believe a crop cannot be planted without ploughing. Farmers' continued insistence to plough, especially down-slope, results in unnecessary soil moisture loss and soil erosion. This leads to either crop failure in the pre-monsoon or missed opportunities to sow a post-monsoon crop.

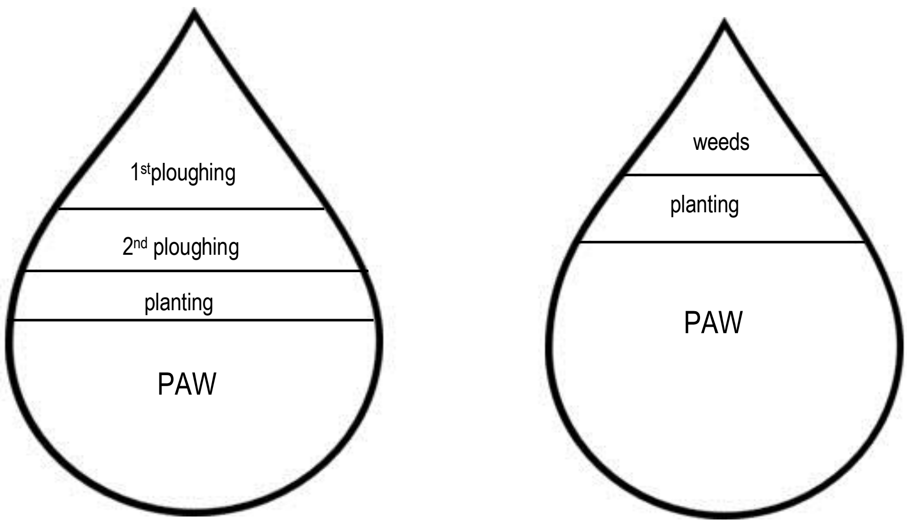

Figure 6-1 Raindrop pictorial of estimated PAW for crop growth in the traditional cropping system (left) compared to the proposed system (right).

This study showed that a few simple adjustments to planting machines or hand planting methods are required to ensure adequate plant populations are achieved under high mulch conditions. The traditional system of hand planting is rapidly being replaced by mechanised planting and harvesting technologies. This allows for a smooth conversion to no tillage technology, which is easier to implement and maintain in a mechanised system. If high rates of adoption of no tillage farming occur in Northwest Cambodia, this research will form the benchmark for best practice guidelines as it is unique to the region.

Feeding crop stover to cattle is a common practice in rice-based cropping systems. This study also assessed the level of mulch required to optimise yield of upland crops and determined that there is no excess mulch available for feeding to livestock. It is believed that the economic benefits of retaining residues in the field outweigh the economic benefits of feeding the residues to livestock. This outcome is an important novel concept for the upland cropping region, which will need to be disseminated to the farming community. The retention of crop residues is practical for farmers to implement and can greatly improve the sustainability of the system from an environmental and economic viewpoint.

6.1.2. Altered sowing windows

This study demonstrated the effectiveness of a shift in sowing time in the pre-monsoon period. In the field, this equates to a planting delay from March to late May. February to April are the hottest three months of the year, and rainfall events are low and unpredictable during this period. Further surveys would be required to reach a definitive answer as to why farmers prefer to plant during this high risk period. However, recommendations as a result of our field research are to plant in late May/early June. Temperatures are cooler at this time and rainfall is increasing in frequency and amount. Aligning sowing date with rainfall and cooler climatic conditions to optimise yield, quality and profit was evident across multiple field trials in this thesis. By sowing at this time, good yields were produced with less risk of crop failure, which resulted in significantly higher gross margin returns. This study has produced extensive sowing time x crop type x yield data which has not previously been collected. These datasets are also considered invaluable for ground-truthing the APSIM model, which has recently been validated for a range of crops grown in this region.

Increasing the cropping intensity of the farming system from two crops per annum to three crops had not been previously tested experimentally in Northwest Cambodian upland production systems. Results from this study however proved it is not possible with currently available crop varieties. Nevertheless, this research did discover that opportunity cropping in response to rainfall and residual soil water is an option for Cambodian farmers. It may be possible to implement a system where farmers plant in response to rainfall amount and estimated stored soil moisture. However, this will require implementation of soil water monitoring techniques such as the APSIM soil water predictor developed in this study, as well as further education of farmers regarding soil water processes.

Conversion to no tillage technology gives farmers the option to successfully grow a crop in alternative sowing windows compared to their traditional sowing times. The new planting windows are late May/early June and October/November. Planting at these times allows plant growth and development to be more closely matched to optimal growing temperatures, whilst utilising stored soil moisture to grow the crop. Traditionally weeds are allowed to grow during this time which results in increased weed burden in subsequent crops and reduced residual soil moisture. Anecdotally, our field trials found that when a crop is actively growing during the post-monsoon, weed burden is reduced due to in-crop weed control and crop competition for water, nutrients and light. The dry nature of the season also reduced the risk of foliar and root diseases. Harvest, drying and storage during the drier weather also increased the ease of post-harvest management. Transport of grain was easier from the farm gate during the post-monsoon with improved road conditions compared to the monsoon season. Marketing of a commodity outside of traditional peak flow periods may also increase the price received. For all these reasons the outcomes of our research recommends a shift in sowing times from the traditional periods of February/March and July/August to the periods of late May/early June and October. This change will increase the sustainability of the farming system through yield stabilisation and improved profit. This is new information for the region which is believed could have wider implications for food security locally. Flow-on effects of increased health and education for farm family members and increased grain production for the region and country are also possible.

6.1.3. Crop sequences

The crop sequence of maize in the pre-monsoon followed by sunflower in an October planting window, was the most productive and profitable crop sequence evaluated by field research in this study. Other successful sequences included continuous maize, maize-soybean-sunflower and maize-soybean-fallow. Farmers in the focus regions of Samlout and Pailin, reported that declining yields and soil fertility were major constraints to production. If farmers retained their crop residues as our study suggests, some nutrients would be recycled back into the soil-water-plant continuum. However the current situation is that almost all crop residues are exported or burnt and what remains after that is then ploughed in. Whilst a rapid rise in fertiliser application of maize crops to combat yield decline has occurred since 2012, continuous maize cropping with no alternative break crop is not considered sustainable for several reasons. Primarily, the amount of nutrients exported in the grain and stover is not replaced sufficiently by the application of fertiliser, which has resulted in observed yield decline. Furthermore, continuous maize much like other cereal monocultures, results in yield decreases over time due to a build-up of pests, weeds and disease in the system. Education of farmers regarding the benefits of traditional legume crops such as soybean, mungbean and peanut, and demonstration of how to incorporate them as successful rotation crops, could help combat decreasing maize yields and soil fertility issues, whilst improving the overall health of the cropping system.

The legume crops, peanut and mungbean, are traditionally grown in this Northwest farming system, however they were not able to be successfully grown in this study. It is recommended that research on these legumes be prioritised to introduce more suitable cultivars into Cambodia with quicker maturity and improved resistance to pests and diseases. Further research is required on options to improve peanut pegging, such as mulching to keep the soil surface moist, under dry soil surface conditions. Since this research was conducted, more environmentally friendly pesticides have become commercially available in Cambodia which assist in control of legume seed borne diseases and insect pests. This will assist in creating a greater variety of crop sequence options such as legumes as alternative crop options. Crop sequence options that may be suitable for farmers in the Northwest region are illustrated below as a two year sequence (Figure 6.2).

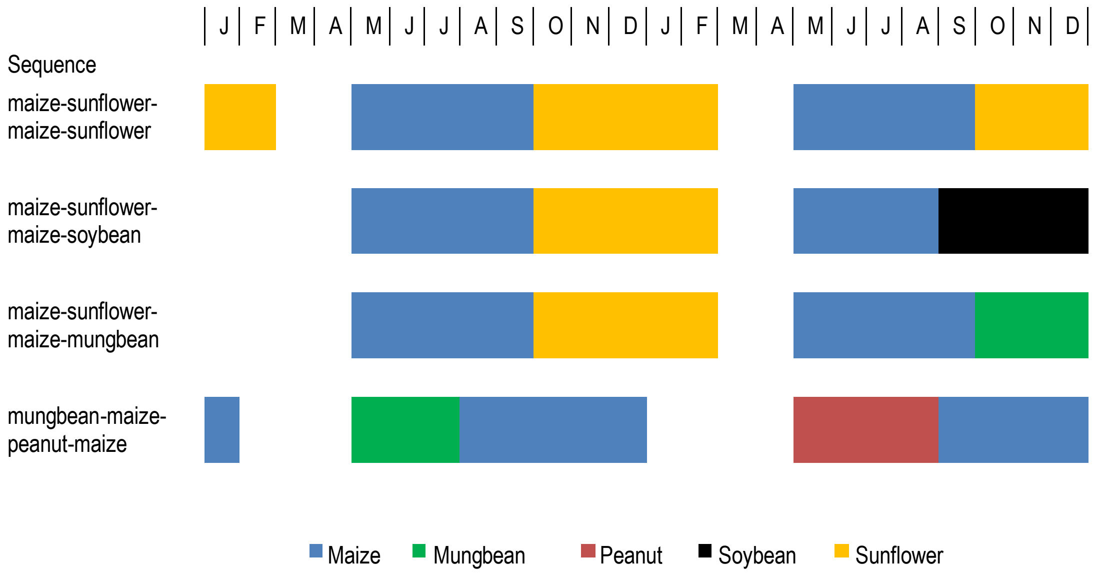

Figure 6-2 Recommended crop sequence options for Northwest Cambodia farming systems for a two year rotation.

In order to successfully implement the maize-soybean sequence in the new recommended planting windows, quicker maturity maize hybrids should be sourced from neighbouring countries. A maize hybrid with 80 days to maturity planted in mid-May would enable harvest in early August and immediate planting of soybean before the mid-August planting window closes. Sequences such as those proposed above would assist to combat soil fertility decline, increase yields and profitability, ultimately resulting in a more sustainable farming system than the current system which is dominated by continuous maize or continuous cassava. Further research on the crop sequences proposed above, using quicker maturing cultivars with improved resistance to pests and diseases is required to fine tune the farming system to make it as efficient as possible in marginal environments.

6.1.4. Integrated farming systems

This research focused on cash crops to increase farmer profitability and intensify production on the existing land area whilst simultaneously improving the sustainability of the farming system. The focus region of Northwest Cambodia, in particular Pailin and Samlout, was until late last century covered by dense rainforest hence it is surmised that permanent tree plantings would also be a sustainable land use option for this region. However this type of agroforestry and horticulture requires financial security to afford the establishment costs of irrigated tree crop orchards, as there is a lag time to viable fruit production. This research provides recommendations to increase the sustainability and viability of cash crops, which have the option to be integrated with permanent tree crops for further sustainability in the region.

The increase in sustainability, profitability and productivity of cash crops will assist in stabilising this part of the agroecological system, which will in turn assist farmers to increase annual farm profits and look to more permanent farming system options. The highest value gross margin in the Samlout region is for durian fruit tree crops and for Pailin, the longan fruit. However, both species require five years to produce viable returns from the trees. Farmers can intercrop cash crops or forages between the trees in the interim to generate income and offset the costs of the orchard establishment. I recommend that future research is focussed on a systems approach centred around landscape suitability based on soil type and slope. Land use as determined by these factors would possibly result in recommendations of cropping on the flat to gently slope terrain, tree crop plantings in undulating hills and sustainable forest management on steeper slopes. This systems approach could investigate the sustainable integration of cash crops and permanent tree plantings in this region. Emphasis should be on agronomic practices to optimise production of both systems and sustainably conserve the natural resource base. Research to date has not been conducted on integrated landscape management in this region. However some farmers are implementing the system and often experience crop failures.

Support in terms of agronomic management practices for optimal sowing times, intercrop plant densities as relates to the age and species of the trees, residue management, soil management, IPM and nutrition are required.

6.1.5. Summary of research

This thesis devised novel techniques to overcome the adverse conditions of conducting research in a remote tropical agricultural environment with limited resources. This extended from the field and lab, to the analysis of data, with advanced statistical methods employed to ensure the variability of the environment was accounted for as accurately as possible. Furthermore, the novel reverse engineering of the APSIM model using our experimental data and surface soil moisture to enable estimation of sub-soil moisture down the profile was of particular note. This is a unique outcome developed in order to overcome the issue of soil sampling in a high risk landmine zone. It has significant implications for conducting soils and agronomic research in all landmine affected countries.

The outcomes of my research are new concepts for Northwest Cambodian farmers, who are disadvantaged by their remote location, lack of education and dearth of Government research and extension services in the region. These outcomes include a shift in sowing time, introduction of a new crop species, sustainable crop rotations, retention of crop residues and estimation of residual sub-soil moisture from surface soil moisture values. These are all quantifiable scientific measures produced by this study and are summarised into a practical farming systems guideline for farmers to improve sustainability of their farming system (Appendix G). These guidelines are designed to be extended to farmers at field days to assist with implementation of practice changes directly derived from the outcomes of my research. There is a requirement for science and technology to be implemented in a rapidly changing system such as Northwest Cambodia, and most importantly the outcomes of the research need to be disseminated. This is especially difficult in Cambodia where the government extension service is poorly resourced and lagging behind in the technological advances of agriculture today. However engagement with the private sector for dissemination of research outcomes has the potential for a future symbiotic relationship. Implementation of these outputs by farmers on a broad scale would result in sustainability improvements at the farm level, and also the health of the wider catchment and downstream communities.

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