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Research Article
Yield Responses of Maize and Sunflower to Mulch under No-till Farming Conditions in Northwest Cambodia

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Abstract

Background: Upland farming in Northwest Cambodia experiences annual soil loss and erosion due to the combination of topography, monsoonal climate and plough based farming practices. This study investigated the potential for no-till farming as a more sustainable farming method in this region. **Methodology:** An experiment was conducted at two sites in neighbouring Northwest provinces to investigate the effects of varying rates (nil, 2.5, 5, 10 and 20 t ha^{-1}) of maize (*Zea mays* L.) stover mulch on yields of maize and sunflower (*Helianthus annus*) using no-tillage farming practices. Small plot replicated experiments were undertaken in the pre-monsoon and post-monsoon seasons. **Results:** The 5 t ha^{-1} mulch treatment attained the highest yield in the pre-monsoonal maize trial. During the post-monsoon period maize yield increased by 0.4 t ha^{-1} with every 2.5 t of mulch applied, whereas nil mulch resulted in near crop failure. Post-monsoon sunflower failed to respond to mulch treatments at either site. The lack of response at the second site which received higher rainfall was probably due to mild seasonal conditions and adequate stored soil water. Maize was more responsive to mulch than sunflower in both seasons with mulch application increasing yield. **Conclusion:** Farmers who retain crop residues increase their chances of establishing a pre-monsoon crop and reduce the probability of crop failure. This study also demonstrated that a successful crop can be grown in the non-traditional sowing period of the post-monsoon. While farmers may not have the resources to justify applying mulch regularly, it is thought they may use the knowledge gained from this study to implement no-till farming practices and retain crop residues *in situ.*

Key words: Conservation agriculture, mulch, upland cropping, *Zea mays*, no-tillage

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Upland farming in the rainfed tropics of Northwest Cambodia has undergone rapid expansion over the last 15 years due to large-scale clearing of rainforest after the civil war[1]. Many farmers in this region are displaced citizens[2] primarily from lowland rice growing regions with scant knowledge of upland crop production[3, 4]. Lack of crop stover retention, cultivation and burning of crop residue has led to a rapid decline in soil fertility and an increase in soil erosion in Northwest Cambodia[1]. Soil erosion is frequently observed after storm events and soil fertility decline is evident in maize crops showing visual signs of nutrient deficiencies particularly N and P. Extensive areas of Southeast Asia's uplands soils have suffered damage due to unsustainable farming practices[5]. In the Northwest provinces of Pailin and Battambang, upland farming systems have decreased in crop diversity over the last 9 years with maize and cassava *(Manihot esculenta)* now the dominant crops at the expense of soybean (*Glycine max* L.), mungbean (*Vigna radiata*), peanut (*Arachis hypogaea*) and sesame (*Sesamum indicum*)[3]. This loss in crop diversity of beneficial legumes with increased maize and cassava plantings will accelerate the decline in soil fertility as legumes assist to stabilise the system, unlike cassava and maize monoculture systems which result in progressive soil C and N losses[6,7]. An increase in continuous maize and cassava cropping has contributed to high rates of soil erosion and runoff in similar Southeast Asian settings but can be alleviated by the implementation of appropriate soil conservation practices[5].

A recent Australian centre for International Agricultural Study (ACIAR) survey highlighted that the majority of farmers in Pailin province and neighbouring Samlout district in Battambang province have observed a decrease in soil fertility but their understanding of the underlying mechanisms or potential remedies is lacking with less than 22% of farmers in these districts supplementing upland crops with fertiliser[3]. Lack of nutrient replacement has resulted in lower maize yields over a 5 year period from an average of 4.1 t ha^{-1} in 2006 to 3.4 t ha^{-1} in 2010[8] . Farmers do not retain crop residues *in situ* after harvest but usually plough or burn crop stover[3] irrespective of the common observation of soil fertility decline and erosion. Only 7% of households applied additional mulch to their fields and 6% added animal manure[3]. Consequently the cumulative effects of these actions are contributing to the appearance of nutrient deficiencies caused by declining soil fertility.

Maize grain yields of 8-10 t ha^{-1} have been achieved in on-farm hybrid evaluation trials and individual farmer fields in Samlout and Pailin, demonstrating that farmers are only realising 40-50% of actual yield potential[9]. The general response to low maize yields has been a shift towards cassava, a crop that tolerates low soil fertility and requires less management allowing household members to seek employment off-farm[10]. However, continuous cassava leads to degradation in soil structural stability, nutrient status and subsequently productivity through nutrient removal and soil erosion losses due to plant architecture, ploughing, wide row configurations and planting rootstock on raised hills[11].

There is evidence for limited adoption of conservation tillage practices in this Northwest region. Farmers now commonly place soybean mulch around fruit trees and maize stover is often used to mulch pumpkins (*Cucurbita* spp.) in Samlout but rarely are these crop residues left standing in the field (personal observations, 2003-2015). However, machine harvesting of maize and soybean began in 2015, so the transition to no-tillage will be easier with uniform crop residue heights post-harvest[12]. Many Pailin maize producers have reduced tillage by replacing the traditional second ploughing with a pre-sowing application of glyphosate spray influenced largely by input costs and scarcity of labour[3,13]. In Kansas, no-tillage increased maize yield by 28% compared to conventional tillage[14] and there are numerous more examples of yield increases worldwide[6,15-18]. Australia now has the highest adoption rate of conservation agriculture globally[19], yet Asia is lagging behind[15] with Cambodia being no exception.

This study proposes that the retention of maize stover mulch in the pre-monsoon cropping season will increase yield of maize and sunflower, whilst post-monsoon preservation of residual soil moisture will also increase crop yield. Usually a crop is not grown in the post-monsoon season[1], however, the researchers hypothesize that through mulch application enough moisture will be conserved to grow a crop at this time. This will widen the potential planting windows, which will enable farmers to make more informed decisions regarding crop choice and planting time to mitigate the risk of crop failure[20]. This study is embedded in an ACIAR project investigating the integration of crop and cattle in Northwest Cambodia and more sustainable crop sequences compared to current farming practices. The maintenance of ground cover is essential in these areas to prevent soil loss and ground cover, crop production and erosion relationships need to be established to assess the value of crop residue retention compared to animal feeding[21]. This study aims to answer the question as to whether retention of maize stover on the soil surface can increase the yield of crops in this farming system and if there is any surplus crop residue that could be fed to cattle.

MATERIALS AND METHODS

Site selection and characterisation: Experiments were conducted at two on-farm sites in Northwest Cambodia (Fig. 1) in 2013. The first site was located 3 km from the town of Pailin (12°52'15" N, 102°36'38" E) on a red brown vertosol[22] at an elevation of 170 m a.s.l. The second site was located on a farm in the vicinity of Kantout village, Samlout district (12°40'7" N, 102°44'43" E), Battambang province on a red dermasol[22] at an elevation of 180 m a.s.l. Soils at both sites have only been described for the surface layer (0-15 cm) as this is the most heavily landmined area of Cambodia and the risk of triggering an anti-tank mine is currently too high to safely undertake full characterisation activities of the soil profile (Bognar pers. comm.). Sites were leased for two years to ensure crop residues were retained and not burnt or ploughed.

An automatic tipping bucket rainfall data logger (Davis Instruments, Model no. 7852M) and maximum/minimum temperature and relative humidity data logger (Lascar Electronics, model no. EL-USB2$^+$) were located on farm at the Samlout site and 3 km away from the Pailin site (at the Provincial Department of Agriculture Building). Seasonal climate data collected for the period of experimentation are summarised in Table 1. Long-term climate data for Pailin and Samlout is limited, with the most reliable data provided from Battambang, situated 90 km away at a lower elevation of 48 m a.s.l and with similar rainfall received as Pailin, yet 39% less rainfall than Samlout.

Northwest Cambodia has a monsoonal climate referred to in this study as having three distinct seasons; the pre-monsoonal period from March-June, the monsoon season from July-October and the post-monsoonal period from November-February. The average annual precipitation at Battambang is 1294 mm with 401, 788 and 105 mm falling in the pre-monsoon, monsoon and post-monsoon periods, respectively (Table 2). Rainfall received across these seasons is summarised in Table 1 and highlights the significantly higher

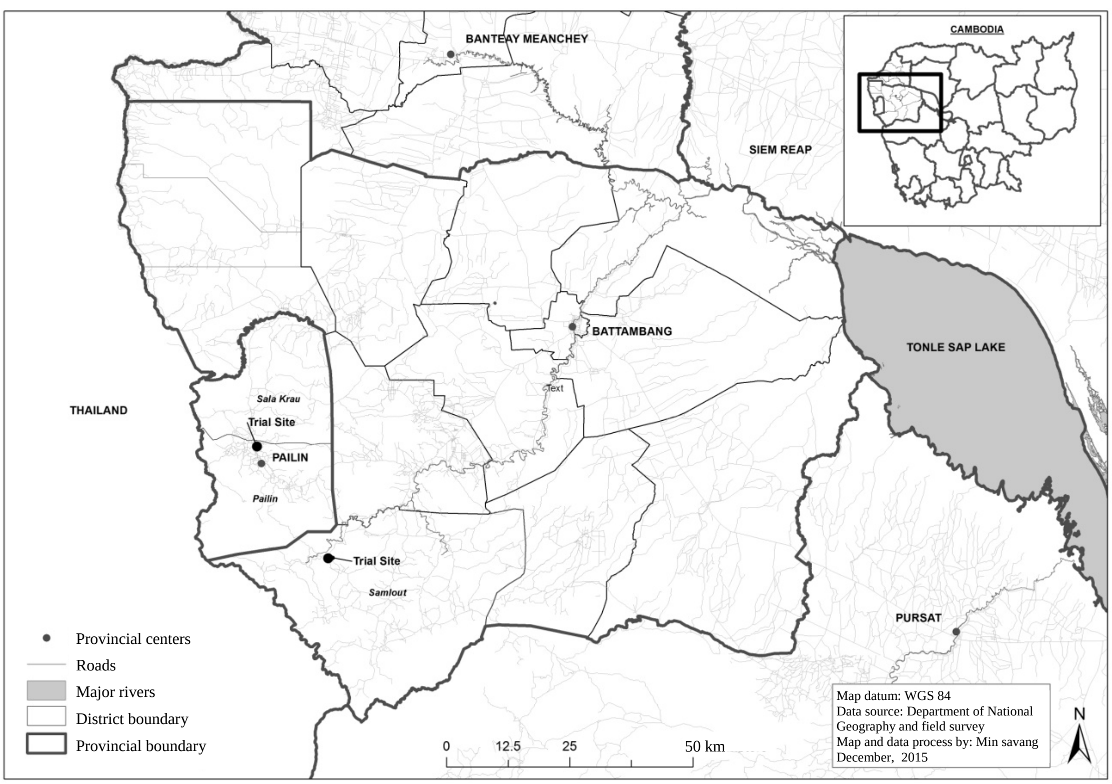

Fig. 1: Map of Cambodia, showing the location of the experimental sites in Pailin district, Pailin province and Samlout district, Battambang province (Min, S., unpublished data)

Table 1: Summary of climate data for three sites in Northwest Cambodia

Site	Variables	Pre-monsoon (March-June)	Monsoon (July-October)	Post-monsoon (November-February)	Annual figure
Battambang †	Mean rainfall (mm)	401	788	105	1294
	Rainfall for the period (mm)	411	826	123	1360
	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 ‡	Rainfall (mm)	247	863	121	1231
	Mean temperature (°C)	30	28	25	27
	Temperature range (°C)	22-53	21-45	13-39	13-53
	Mean relative humidity (%)	70	76	71	73
	Relative humidity range (%)	30-97	40-98	26-97	26-98
Samlout ‡	Rainfall (mm)	514	1417	201	2132
	Mean temperature (°C)	29	27	24	27
	Temperature range (°C)	21-46	20-48	8-37	8-48
	Mean relative humidity (%)	79	84	77	80
	Relative humidity range (%)	37-99	36-98	27-99	27-99

†Battambang data are long term averages from 1982-2015 from Veal Bek Chan Meteorology station, Battambang city, except for actual rainfall for the period June, 2013 to May, 2014, ‡Climate data for Pailin and Samlout is for June, 2013 to May, 2014

Table 2: Crop inputs and calendar of operations for all three mulch trials in 2013

			Date of operation		
Input/activity	Crop	Rate of application	Pailin pre-monsoon	Pailin post-monsoon	Samlout post-monsoon
Sowing date	All		21-03-13	13-11-13	14-11-13
Glyphosate (480 g L^{-1})	All	2.4 L ha^{-1}	14-03-13	14-11-13	07-11-13
Paraquat (27-6% w/v)	All	2.4 L ha^{-1}	21-03-13	13-11-13	14-11-13
KCl fertiliser (0:0:60)	All	100 kg ha^{-1}	21-03-13	13-11-13	14-11-13
Starter fertiliser (16:20:0+TE)	All	100 kg ha^{-1}	21-03-13	13-11-13	14-11-13
Urea (46:0:0)	All	100 kg ha^{-1}	26-04-13	na	na
S-Metolachlor (960 g L^{-1})	Maize	2 L ha^{-1}	21-03-13	13-11-13	14-11-13
Atrazine (800 g kg^{-1})	Maize	0.4 kg ha^{-1}	25-04-13	19-12-13	20-12-13
Hand weeding	All	na	16-05-13	December	December
			12-06-13	February	February
Harvest	All	na	16-07-13	24-03-14	11-04-14

na: Not applicable to that operation

rainfall received at Samlout (2132 mm) which is 838 mm more than the Battambang long-term average rainfall and 901 mm more rain than Pailin (1231 mm) for the same period.

The average annual air temperature at Battambang is 28°C. Pre-monsoon is the hottest season with an average daily temperature of 30°C and post-monsoon is the coolest with an average daily temperature of 26°C. Average daily relative humidity at Battambang is 80% with extremes ranging from 62-95% throughout the year. Seasonal patterns were similar at Pailin except for larger fluctuations in temperature meaning it was warmer in the pre-monsoon and cooler in the post-monsoon. The annual average temperature for Pailin was 27°C, however, the range extended from a low of 13°C in the post-monsoon and reached up to 53°C in the pre-monsoon. The mean relative humidity at Pailin was lower at 73% and with more variation in humidity experienced throughout the course of the year, ranging from 26-98%. The annual average temperature at Samlout was 27°C with large diurnal variation in temperature across all seasons. Samlout experienced generally cooler nights than the other two sites, down to a low of 8°C in the post-monsoon, yet still experienced temperatures up to a maximum of 46°C in the pre-monsoon. Relative humidity averaged 80% with a range of 27-99%.

Experimental design: The experiment was arranged in a split plot design with five main plot treatments of rates of applied maize stover mulch at 0, 2.5, 5, 10 and 20 t ha^{-1} at each site. The split plot treatments within these main plots were the crop species, maize and sunflower, with a plot size of 4×6 m at Pailin and 4×5 m at Samlout and a row spacing of 1 m. The trial consisted of three replicates nested within the main plot. In total, three experiments were undertaken at two different locations. The first trial was sown at the Pailin site on 20-21st March, 2013 at the break of season for the pre-monsoon. Due

Table 3: Soil chemistry variables† of the two trial sites, Pailin and Samlout

Variables	Pailin‡	Samlout§
pH H_2O1:5	7.3 (0.09)	7.1 (0.07)
EC H_2O 1:5 µS cm^{-1}	145 (12)	175 (12)
Colwell P mg kg^{-1}	27 (4)	71 (5)
KCl 40-S mg kg^{-1}	19 (1)	28 (1)
Boron	0.9 (0.1)	1.2 (0.2)
Exchangable Ca^{2+} cmol kg^{-1}	28.0 (2.2)	17.8 (0.6)
Exchangable K^+ cmol kg^{-1}	0.5 (0.1)	1.7 (0.2)
Exchangable Mg^{2+} cmol kg^{-1}	7.9 (0.3)	5.3 (0.2)
Exchangable Na^+ cmol kg^{-1}	0.03 (0)	0.02 (0)
Organic C (%)	2.1 (0.09)	3.4 (0.11)
Total N (%)	0.21 (0.01)	0.31 (0.02)
Field capacity (% by volume)¶	54 (0.6)	33 (0.4)
Permanent wilting point (% by volume)¶	27 (0.2)	22 (0.2)
Plant available water capacity¶ (mm/10 cm layer)	26.8 (n/a)	11.1 (0.49)
Bulk density$^\beta$	1.31 (0.13)	0.92 (0.03)
Texture (sand:silt:clay)$^\beta$	32 (0.62): 12 (0.32): 56 (0.94)	11 (0.13): 22 (0.23): 66 (0.08)

†Standard errors are reported in parentheses following treatment means for variables, ‡n: 13 for chemistry analysis, §n: 6 for chemistry analysis, ¶n: 3 for Pailin and n: 6 for Samlout, $^\beta$n: 2

to dry conditions at Samlout the second trial site could not be sown in the pre-monsoon. However, a trial was sown at each site during the post-monsoon in November, 2013. All experiments contained identical treatments.

To ensure uniformity across the treatments, all residues were removed from the trial area before sowing. For the initial trial, the maize stover was hand cut at approximately 15 cm height above soil surface, from a recently harvested field and transported to the field site, where it was weighed onto the plots to the required treatment rate. The stover was applied after sowing and remained as whole unsegmented stalks. However, for the remaining two trials, the mulch treatments were applied first and the crops sown after. The mulch material was cut and chopped with a stalk chopping machine at a height of 15 cm, to produce a sample that consisted of segments which were approximately five centimetres in length and was applied for the two post-monsoon experiments.

Agronomic trial management: Agronomic practices were selected to be as consistent as possible across treatments and in keeping with regional farmer practice but under no-till conditions. Details of trial inputs and the timing of operations are summarised in Table 2.

Varietal choice for the crops sown was limited to seed availability in the region. For maize the seed Asia hybrid SA345, a common hybrid recommended in the region[23] was planted in all of the trials. This is a common hybrid choice for farmers in the region. Sunflower seed was sourced from Thailand and was a Pacific seeds hybrid, Olisun 3, which has been grown in both districts as part of a fledgling oil industry. The hybrids for both crop types are well adapted to the Northwest Cambodian upland (Martin R., pers. comm.). All trials were planted and harvested by hand and pesticide applications were applied by knapsack sprayer with a 2 m swath width. Target planting depth was 2.5 cm deep. Starter fertiliser (Table 2) was banded on the soil surface adjacent to the planted row immediately post-sowing. For maize, top-dressing of N was applied 20 days after sowing and was banded in a row 5 cm parallel to the plant line.

Sample collection and processing: Prior to sowing, surface soil samples of 0-15 cm were taken across the trial areas totalling 13 samples at Pailin and 6 samples at Samlout, which were analysed for chemical properties by the University of New England (UNE) soil laboratory, situated in Armidale Australia. The analysis included pH (method 4A1), EC (method 3A1), organic C (method 6B3), total N (method 7A5), P, S (method 10D1 KCl-40), B (method 12C1), exchangeable cations of Ca^{2+}, Mg^{2+}, K^+ and Na^+ (method 15A1)[24]. Methods for EC and pH were measured using 1:5 soil to solution extracts in water. Extractable P was analysed via malachite-green spectrophotometry after Colwell[25] extraction and exchangeable cations via inductively coupled plasma optical emission spectroscopy (ICP-OES) after 1 M NH_4Cl extraction. Organic C and total N were analysed using the LECO CN analyser. The means of all analysis are summarised in the results (Table 3).

After final harvest at the site, two soil samples (0-15 cm depth interval) were taken to estimate bulk density, which was conducted using two replicates per sample, following the microwave method[26]. Plant Available Water Capacity (PAWC) was determined using the pressure plate extraction method, with three replicates of each sample tested at equilibration pressures of 10 and 1500 kPa (Soil Moisture Equipment Corp. 1, 5 and 15 bar plates). Plate water efflux was monitored until stable for 48 h, at which time samples were weighed and oven dried at 105°C until constant mass was achieved[26,27]. Plant available water holding capacity was calculated as the difference between water held at field capacity (-10 kPa) and water content at permanent wilting point (-1500 kPa)[28]. This figure was then extrapolated using the surface soil bulk density to estimate the potential PAWC for the soil profile down to 1.2 m as the other soil layers were not able to be sampled.

Grain harvest was taken from the internal rows of each plot. The external buffer row on either side of each plot was used for biomass cuts. At harvest, two biomass samples were collected from each subplot; sample A consisted of five consecutive plants taken from the outermost row on the western side of each subplot and sample B consisted of five consecutive plants taken from the corresponding row on the eastern side. A sub-sample of four of the plants from each of the A and B samples were measured for total fresh weight of plant biomass and cob/head weight. The same measurements were recorded for the remaining single plant from each of the A and B samples, along with the additional parameter of plant height. For sunflower, head diameter was also recorded on the single plant samples. The single plant was then dried, which resulted in each plot having two subsample single plants, A and B. After drying, biomass weights of plant stover, cobs or heads and seed were recorded again, along with cobs per plant, seeds per plants, seed weight and grain moisture in order to estimate harvest index and calculated as the ratio of seed weight to total biomass.

Initially samples were dried in a microwave oven using methods adapted from Marur and Sodek[29], the Nitrate Elimination Company Inc.[30], Smith[31] and Wang *et al*.[32]. Samples were microwaved at 80% power load and weighed every 1-3 min depending on the sample type, until a constant mass was achieved consecutively. In 2014, an open dryer fuelled by rice husks was sourced for the purpose of drying samples. The dryer was run at approximately 40°C for 6 h each day (8-11 am and 1-4 pm) over a 2 day period. Samples were then removed, reweighed and moisture tested (Wile, model no. 65). This was established to be a suitable time frame based on a pilot run of the dryer over a 2 day period, where plant stover and grain samples of each crop type were individually weighed and the grain was moisture tested, every hour, excluding the lunch break, from 8 am to 4 pm and repeated again the next day. Most samples reached constant weight and moisture within 7-10 h of drying.

Data processing and analysis: Each trial and crop was independently analysed and is reported on separately. Analysis were undertaken using R for windows version[33] 3.2.2. The effect of mulch application on yield was first examined via a mixed linear model approach using the nlme package[34] to account for the nesting structure of the trials. Including curvature in the model estimation did not improve the model fit and as such a linear response was modelled. Where overall significant differences were found, simple pairwise comparisons of treatments were made via the general linear hypothesis (Tukey's) approach as described by Hothorn *et al*.[35]. To then assess the additional influence of plant population on yield, the above model was subsequently extended to include mulch rate as a systematic categorical variable and plant density as a covariate, using the same nesting structure. Significance of mulch, plant density and the interaction of these were taken at the $p<0.05$ level. Where either of the above analysis indicated a trend of increasing yield with mulch rate, this was also expressed as a yield increase across tonnage increase of mulch for convenience, along with the adjusted R^2 value from the mixed model.

In addition to the above, the mixed model approach described above was used to analyse the association of each of the agronomic variables of plant density, plant weight, plant height, head diameter, seed weight, cob number, seed number and harvest index with mulch application rate. Following exploration of potential bivariate associations, a potential association was identified between plant height and yield. A Pearson's product-moment correlation test[36] was used to analyse this interaction. All model assumptions for all analysis were tested and met.

RESULTS AND DISCUSSION

Soil analysis: Soil analysis from the experimental sites revealed neutral pH levels and non-limiting levels of P, K, S and EC for crop growth (Table 3). Soil texture was determined as clay[37].

Soil PAWC was determined in the surface layer to be 26.8 mm per 10 cm increment at Pailin and 11.1 mm per 10 cm increment at Samlout. From this, the soil profile was estimated to have the capacity to hold 321 mm at Pailin and 133 mm at Samlout of plant available water assuming plants roots can access to 1.2 m deep and bulk density remains constant down the soil profile.

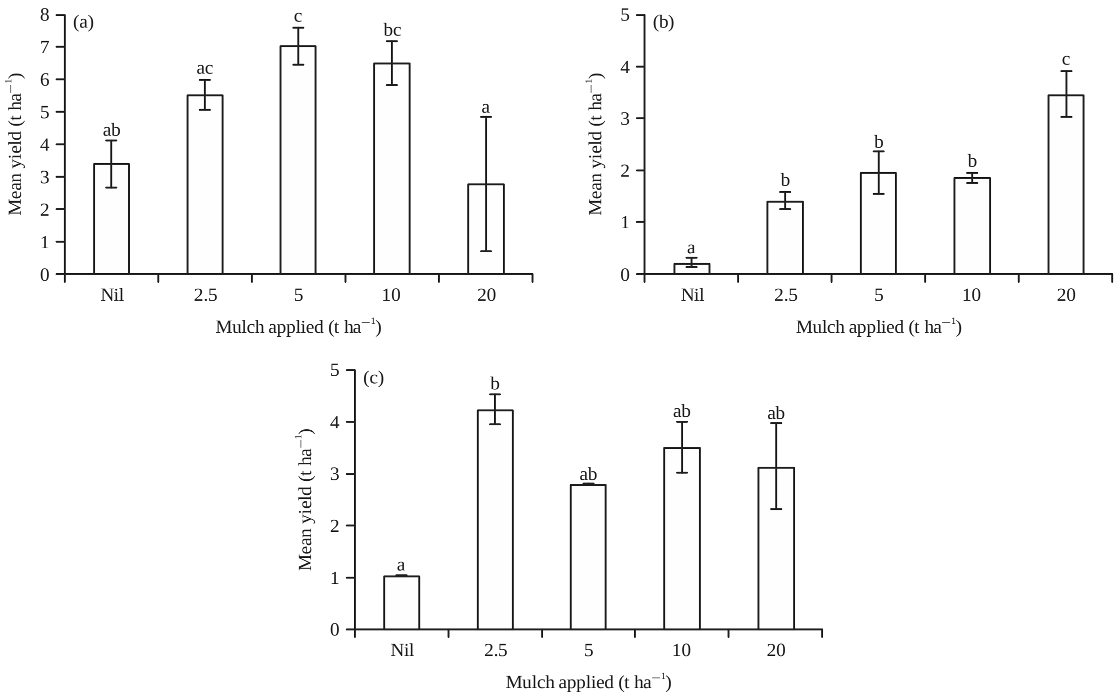

Fig. 2(a-c): Effect of maize stover mulch on mean yield of maize at (a) Pailin pre-monsoon 2013, (b) Pailin post-monsoon 2013 and (c) Samlout post-monsoon 2013. Bars with different letters denote significant differences at p<0.05

Maize yield: Differing results were obtained from the three maize trials conducted (Fig. 2). Maximum yield from the pre-monsoon maize trial at Pailin (Fig. 2a) was 7 t ha^{-1} in the 5 t ha^{-1} ($p = 0.03$) mulch treatment. Response to mulch was lowest from the treatments of nil mulch and 20 t ha^{-1} mulch ($p = 0.005$), which were 52 and 61% lower yielding than the 5 t ha^{-1} treatment, respectively.

Post-monsoon maize yield at Pailin was highly correlated with mulch rate, increasing from an almost crop failure of 0.22 t ha^{-1} in the nil treatment ($p<0.001$), to a maximum yield of 3.5 in 20 t ha^{-1} ($p<0.001$) rate of mulch applied. This equated to an increasing maize yield of 0.4 t ha^{-1} for every 2.5 t ha^{-1} of mulch applied ($R^2 = 0.87$, $p<0.01$). The middle three treatments of 2.5, 5 and 10 t ha^{-1} mulch ranged from 1.4-1.9 t ha^{-1} grain yield (Fig. 2b). Post-monsoon maize at Samlout had only one plot each for the nil and 5 t ha^{-1} treatments as the other two replicates were damaged by herbicide spray drift. All treatments responded positively to mulch with the 2.5 t ha^{-1} mulch applied treatment yielding the highest at 4.2 t ha^{-1} ($p = 0.005$) compared to the nil mulch treatment which produced only 1 t ha^{-1} grain yield (Fig. 2c).

Sunflower yield: The effect of mulch on sunflower yield was less apparent than for maize. Application of mulch had no effect on sunflower yield at either site or season ($p>0.05$) (Fig. 3). Whilst yield differences were not significant there was an upward yield trend of 0.5 t ha^{-1} with every 10 t ha^{-1} of mulch applied in the post-monsoon season at Pailin ($R^2 = 0.74$, $p = 0.06$).

Table 4: Yield response of maize and sunflower to differing levels of mulch and plant populations at Pailin and Samlout

Trial	Mulch rate	Population	Mulch*population
Maize			
Pailin pre-monsoon	**	**	ns
Pailin post-monsoon	**	ns	ns
Samlout post-monsoon †	ns	ns	ns
Sunflower			
Pailin pre-monsoon	ns	ns	ns
Pailin post-monsoon	ns	**	ns
Samlout post-monsoon †	ns	ns	ns

† Samlout post-monsoon maize has no nil or 5 t ha^{-1} rates in analysis as only 1 data point per treatment due to spray drift, *,**Significant treatment effects at $p\leq 0.05$, $p\leq 0.01$, ns: Not significant

Plant populations for maize: Plant density in maize was a covariate due to mulch impacting on emergence and establishment. Mixed model analysis results (Table 4) show that the only trial to have yield responses to both mulch and population was conducted at Pailin in the pre-monsoon, where the target plant density for maize was 30,000 plants ha^{-1}. The association between yield and plant density was strong and consistent across mulch rates (Table 4), where maize yield increased in proportion to plant

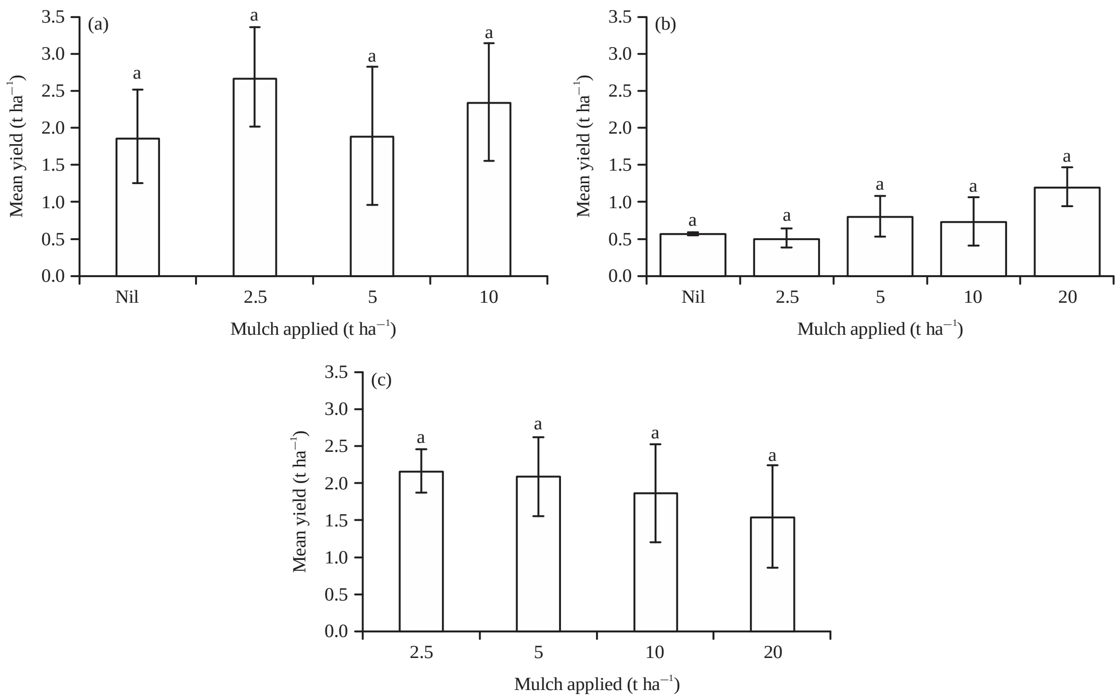

Fig. 3(a-c): Maize stover mulch effects on mean yield of sunflower at (a) Pailin pre-monsoon 2013, (b) Pailin post-monsoon 2013 and (c) Samlout post-monsoon 2013. Bars with the same superscript letters denotes no significant difference ($p>0.05$) in yield between treatments

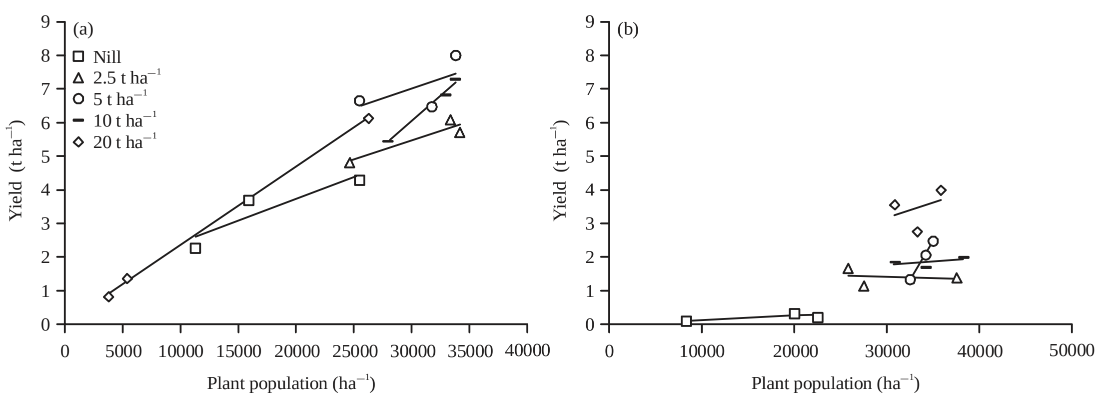

Fig. 4(a-b): Effect of mulch and plant population on the yield of maize, (a) Pailin pre-monsoon and (b) Pailin post-monsoon. Experimental values are plotted as different symbols for each mulch treatment. Linear trend lines are plotted as solid lines

density and this trend was consistent across mulch rates (Fig. 4a). The 20 t ha^{-1} mulch rate in particular was associated with poor emergence, resulting in the lowest plant establishment compared to all other rates except for the nil treatment ($p<0.05$). The nil and 20 t ha^{-1} mulch rate failed to meet the target plant density which resulted in yield reductions, while all other treatments met the target plant density. Yields increased by 2.3 t ha^{-1} for every 10,000 plants established above the 20 t ha^{-1} mulch population up to the highest yield of 7 t ha^{-1} in the 5 t ha^{-1} treatment ($R^2 = 0.89$, $p<0.01$) (Fig. 4a).

For the post-monsoon maize trial at Pailin, addition of mulch at all rates resulted in increased plant populations ($p<0.01$), in so much that yield increased under nil mulch to

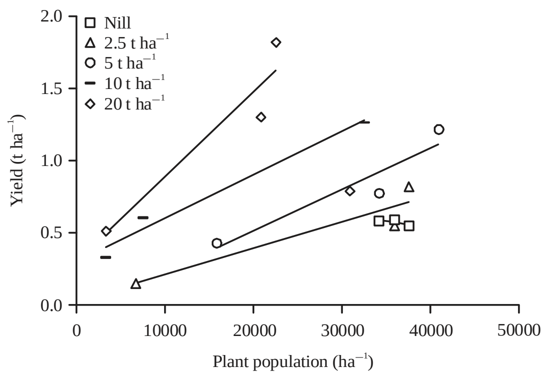

Fig. 5: Effect of mulch and plant population on the yield of sunflower at Pailin post-monsoon 2013. Experimental values are plotted as different symbols for each mulch treatment. Linear trend lines are plotted as solid lines

20 t ha^{-1} mulch at a rate of 1.98 t ha^{-1} for every 10,000 plants established above the nil treatment population density ($R^2 = 0.45$, $p<0.01$) (Fig. 4b). However, it was mulch rate that had the greatest effect on yield in this trial (Table 4). At Samlout, only three treatments were able to be analysed due to spray drift leaving only one replicate in each of the nil and 5 t ha^{-1} treatments, so they were excluded from population analysis. The highest plant density and subsequent yield achieved was at the mulch rate of 2.5 t ha^{-1} ($p<0.05$). As plant density increased so too did yield with 0.8 t ha^{-1} of yield gained for every 10,000 extra plants established; however, this was not a significant response ($R^2 = 0.67$, $p>0.05$).

Plant populations for sunflower: Plant density was not related to mulch application in sunflower ($p>0.05$), however, it did have an effect on yield at Pailin in the post-monsoon. The target plant density for sunflower across sites and seasons was 25,000 plants ha^{-1} which was achieved in approximately half the treatments at Pailin, whilst the majority of treatments at Samlout achieved establishment above the recommended plant density. The only trial where population had a significant effect on yield was at Pailin in the post-monsoon (Table 4), where yield increased by 0.5 t ha^{-1} for every 10,000 plants established below the maximum population of 36,000 plants ($R^2 = 0.12$, $p<0.01$) (Fig. 5).

Maize plant characteristics and yield components: Plant characteristics including total plant weight and height are summarised in Table 5, along with yield components of cob number, seed number, seed weight and Harvest Index (HI). The only yield component that produced a response to mulch in the pre-monsoon at Pailin was mean Hundred Seed Weight (HSW) in which the 20 t ha^{-1} rate of mulch produced the heaviest seed compared to nil ($p = 0.02$) and 10 t ha^{-1} ($p<0.001$) rates (Table 5). For post-monsoon season maize at Pailin, all measured plant and yield components responded to the application of mulch except for HI (Table 5). Variables measured showed a positive response to increasing rates of mulch applied with the exception of mean HSW which was higher in the nil and 20 t ha^{-1} treatment compared to the other mulch rates. Plant height and yield had a strong correlation so that for every 10cm gained in plant height, yield increased by 0.53 t ha^{-1} ($R^2 = 0.93$, $p<0.0001$). The number of cobs per plot was only recorded for the post-monsoon at Pailin with a positive response to all mulch rates applied compared to the nil control ($p<0.0001$). Furthermore, the number of seeds per cob in the 20 t ha^{-1} treatment was 3.3 times that of the nil mulch treatment ($R^2 = 0.6$, $p<0.001$).

At Samlout, maize HI responded to mulch application whereby the nil mulch treatment was 66% less than the 2.5 t ha^{-1} ($p<0.001$) and 5 t ha^{-1} ($p<0.01$) treatments; 40% less than 10 t ha^{-1} ($p = 0.08$) and 26% lower than 20 t ha^{-1} ($p>0.05$) (Table 5). Seeds per cob also responded to mulch which resulted in less seeds produced per cob for nil compared to 2.5 ($p<0.001$), 5 t ha^{-1} ($p<0.05$) and 10 t ha^{-1} ($p<0.01$) mulch rates.

Sunflower plant characteristics and yield components: Plant characteristics including total plant weight and height are summarised in Table 6, along with yield components of seed number, seed w eight, head diameter and HI. In the pre-monsoon, there were no plant characteristics or yield components that exhibited a response to mulch for sunflower. However in the post-monsoon at Pailin, the nil ($p<0.05$) and 2.5 t ha^{-1} ($p<0.01$) mulch rates resulted in shorter plant height compared to the other treatments, with yield increasing by 0.32 t ha^{-1} for every 10 cm gain in plant height ($R^2 = 0.43$, $p>0.05$). Plant height data was not recorded for the trial at Samlout. In the post-monsoon at Pailin, seeds per head showed a positive mulch response with the nil ($p = 0.006$) and 2.5 t ha^{-1} ($p = 0.04$) treatments producing less seeds per head than the 10 t ha^{-1} treatment. At Samlout, the 2.5 t ha^{-1} and 20 t ha^{-1} mulch treatments resulted in heavier plants than the 5 t ha^{-1} ($p<0.001$) and 10 t ha^{-1} ($p<0.001$) treatments but were not different to each other. Harvest index was significantly less for 20 t ha^{-1} mulch compared to the 2.5 t ha^{-1} ($p = 0.02$) and 10 t ha^{-1} ($p = 0.007$) treatments. Mulch application did not affect HSW across any of the trials.

Table 5: Average results for yield components and plant characteristics for maize across all trials[#]

Rate of mulch applied	Mean whole plant weight (g)	Mean plant height[§] (cm)	Mean HSW[†] (g)	Mean cobs/plot[‡]	Mean seeds/cob	Mean harvest index
Pailin pre-monsoon[†]						
Nil	400[a]	162[a]	37.81[a]	na	359[a]	0.50[a]
2.5 t ha^{-1}	520[a]	187[a]	39.85[ab]	na	455[a]	0.54[a]
5 t ha^{-1}	527[a]	212[a]	26.91[a]	na	445[a]	0.51[a]
10 t ha^{-1}	563[a]	215[a]	35.98[a]	na	483[a]	0.48[a]
20 t ha^{-1}	740[a]	191[a]	44.24[b]	na	423[a]	0.47[a]
Pailin post-monsoon						
Nil	60[a]	132[a]	25.55[b]	10[a]	99[a]	0.27[a]
2.5 t ha^{-1}	120[b]	160[b]	19.61[a]	31[b]	179[b]	0.53[a]
5 t ha^{-1}	161[bc]	176[c]	20.51[a]	37[b]	263[c]	0.57[a]
10 t ha^{-1}	167[c]	167[bc]	22.69[ab]	37[b]	161[ab]	0.44[a]
20 t ha^{-1}	235[d]	194[d]	25.98[b]	37[b]	327[c]	0.49[a]
Samlout post-monsoon[¶]						
Nil	272[a]	na	41.16[a]	na	115[a]	0.16[a]
2.5 t ha^{-1}	346[a]	na	37.42[a]	na	456[c]	0.47[c]
5 t ha^{-1}	348[a]	na	40.59[a]	na	404[bc]	0.47[bc]
10 t ha^{-1}	296[a]	na	30.44[a]	na	346[bc]	0.35[ac]
20 t ha^{-1}	248[a]	na	27.52[a]	na	268[ab]	0.28[ab]

[†] Results exclude 1 replicate of 5 t ha^{-1} treatment due to rat damage and 1 replicate of 20 t ha^{-1} due to mould for Pailin pre-monsoon analysis of Hundred Seed Weight (HSW), [‡] Cobs per plot were not measured at Pailin pre-monsoon and Samlout, [§] Plant height was not measured Samlout, [¶] All analysis at Samlout contain only 1 replicate each for both nil and 5 t ha^{-1} treatment due to spray drift, [#] Different superscript letters denote significant differences between treatments ($p<0.05$) and na: Measurements not taken

Table 6: Average results for yield components and plant characteristics for sunflower across all trials[§]

Rate of mulch applied	Whole plant weight (g)	Plant height (cm)	Head diameter (cm)	HSW (g)	Seeds/head	Harvest index
Pailin pre-monsoon[†]						
Nil	573[a]	142[a]	20[a]	6.16[a]	1461[a]	0.48[a]
2.5 t ha^{-1}	523[a]	151[a]	21[a]	6.37[a]	1360[a]	0.41[a]
5 t ha^{-1}	807[a]	136[a]	20[a]	6.19[a]	1139[a]	0.41[a]
10 t ha^{-1}	691[a]	146[a]	21[a]	6.86[a]	951[a]	0.39[a]
Pailin post-monsoon						
Nil	45[a]	102[a]	13[a]	7.70[a]	134[a]	0.25[a]
2.5 t ha^{-1}	100[a]	100[a]	13[a]	6.40[a]	245[a]	0.34[a]
5 t ha^{-1}	85[a]	129[b]	17[a]	7.70[a]	460[ab]	0.37[a]
10 t ha^{-1}	124[a]	131[b]	20[a]	7.69[a]	809[b]	0.25[a]
20 t ha^{-1}	157[a]	132[b]	19[a]	7.04[a]	605[ab]	0.36[a]
Samlout post-monsoon[‡]						
2.5 t ha^{-1}	733[b]	na	26[a]	7.69[a]	1994[a]	0.32[b]
5 t ha^{-1}	412[a]	na	26[a]	7.69[a]	1905[a]	0.27[ab]
10 t ha^{-1}	381[a]	na	26[a]	7.69[a]	1771[a]	0.34[b]
20 t ha^{-1}	852[b]	na	26[a]	7.69[a]	1643[a]	0.15[a]

[†] Results exclude 20 t ha^{-1} treatment for Pailin pre-monsoonas no plants successfully established, [‡] Results exclude nil treatment for Samlout post-monsoon, [§] Different superscript letters denote significant differences between treatments ($p<0.05$)

Visual observations: Throughout the pre-monsoon growing season sunflower and maize plants exhibited stunted growth, wilted or dull leaf appearance and faster phenological development, including a shortened flowering period, which culminated in earlier maturity in the nil and 2.5 t ha^{-1} treatments. Plants in the other treatments did not have visual symptoms of stress. In the post-monsoon trial at Pailin plant stress was observed in all crops and treatments with the exception of the 20 t ha^{-1} rate. Visual plant stress signs were the same as for the pre-monsoon season, in addition to premature leaf margin necrosis and small heads or cobs. These physical signs of plant stress were especially evident in the nil and 2.5 t ha^{-1} treatments, along with poor root development which was also associated with some plant lodging during the growing season.

Influence of mulch on soil erosion, structure and fertility: These trials have demonstrated that by conserving crop residues in the pre-monsoon and post-monsoon yield can be significantly increased for maize and whilst not significant there was an upward yield trend for sunflower at Pailin. Initial soil water is unknown, however an estimate of the potential plant available water content of the soil was calculated from each soil's moisture release curve. At Samlout, there was no grain yield response to mulch, which may in part be due to the fact this site received more rainfall than the Pailin site and hence that this trial started with a fuller soil profile of moisture, which may be approximately 131 mm of available soil water down to a depth of 1.2 m. This further supports the hypothesis that with preservation of soil moisture, appropriate crop choice and time of sowing, a post-monsoon crop can be successfully grown on residual soil moisture alone[38].

Study in both tropical and temperate soils has found that in long term no till systems where crop residues were retained, levels of soil nutrients were greater, including soil organic C, total N and in some instances extractable P, in the soil surface layer compared to conventional ploughing methods that result in residue being removed or incorporated into the soil[18,39-41]. The retention of crop residues combined with minimal soil disturbance has long-term benefits of less soil erosion and the stabilisation of soil organic C and soil fertility[15,42]. From these study results the authors surmise that once mulch was added to the soil surface, it helped to retain moisture in the soil, reduce soil temperature, allow greater infiltration of occasional rainfall events which lessened runoff and potentially provided greater plant transpiration efficiency[6,43]. It is not clear from these mulch trials in Northwest Cambodia which of the above factors contributed the greatest influence on the results, hence further study needs to be conducted to clarify the effect of mulch on soil moisture, soil temperature, infiltration rate of water into the soil, soil physical properties and the longevity of mulch throughout the Cambodian post-monsoon period.

Influence of mulch on crop establishment: The results of this study highlighted that traditional farming practices of not retaining residues (nil mulch) restricts plant emergence and establishment, which prevents farmers from achieving optimal plant populations and places a limit on the achievement of potential yields. For both crops, the pre-monsoon treatments of nil and 20 t ha^{-1} resulted in low plant stands. In the nil treatment, the bare earth quickly turned into a hard-set, dry soil, which subsequently restricted seedling emergence and establishment. For the mulch treatments of the pre-monsoon trial stover was applied as whole maize plants. This created a thick layer of material, which caused difficulties for crop emergence in some of the treatments. Pre-monsoon sunflower experienced severe emergence problems due to the mulch layer thickness and this resulted in notably lower yield for two replicates of the 5 and 10 t ha^{-1} rates and zero emergence for all of the 20 t ha^{-1} mulch replicates. Maize emergence was higher, hence low plant densities and yields only occurred for the highest rate of mulch. The other mulch rates did not affect establishment, implying there can be too much mulch in the system if not handled correctly.

For both post-monsoon trials the mulch application preceded sowing which resulted in better plant establishment because the mulch was disturbed slightly by planting which provided a better pathway for seedlings to emerge. Post-monsoon maize trials at both sites had lower established plant densities in the nil mulch treatments compared to all other treatments with mulch added. Planting into bare ground (nil mulch) failed to reach target plant populations, whereas the addition of any rate of mulch increased plant densities, most likely due to the creation of a more favourable environment by the mulch retaining moisture for longer, which provided protection and cooler temperatures to assist normal seedling establishment.

Influence of mulch on plant growth and development: In the nil mulch treatment for both crops and seasons, maximum yield was capped even when an adequate population density of 30,000 plants ha^{-1} was reached. This yield cap was most likely due to less available moisture with no mulch cover and more days of plant stress during the growing season. The plants in the nil mulch treatment showed visual signs of moisture stress in the form of stunted growth, accelerated plant development, shortened flowering period, wilting during the day, dull bluish leaf colour, smaller heads or cobs, leaf margin necrosis and poor root development. Plant stunting and drought stress was visually obvious in maize and sunflower in both seasons but it was particularly evident in the post-monsoon season at Pailin, where for maize there was a yield response of 0.53 t ha^{-1} increase with every 10 cm increase in plant height and for sunflower it was 0.32 t ha^{-1} yield increase per height increment. Numerous studies have found that sunflower yield increases with increasing plant height[44-46], however, Hladni *et al.*[47] could not confirm this with only a slight positive correlation between plant height and seed yield. For the post-monsoon trials at Pailin, plant height was a strong indicator of yield in maize but the correlation was weaker for sunflower.

Post-monsoon results for maize at Pailin suggest that the nil mulch plants were stressed throughout the entire growing season; from initial establishment problems to low biomass production and subsequently small cobs[48]. The plant was affected by early water stress to produce a low yield and thus only managed to fill a small number of seeds[49]. In contrast, the 20 t ha^{-1} mulch treatment, which met the planting density target, produced high biomass and large cobs with a high number of well filled seeds per cob to produce the highest yield. By adding 20 t ha^{-1} mulch to the field, seeds per cob were increased by 3.3 times compared to the nil mulch treatment and yield increased by 0.4 t ha^{-1} for every 2.5 t of mulch added. This supports our hypothesis that mulch helps retain soil moisture and reduce evaporation and surface soil temperatures, thus reducing plant stress and providing extra residual soil moisture for plant growth and grain production compared to where the crop is growing on bare soil.

Seeds per plant is strongly correlated with seed yield and oil content in sunflowers[47,50]. Post-monsoon sunflowers at Pailin exhibited a positive response to mulch for seeds per head, where nil and 2.5 t ha^{-1} mulch treatments produced less seeds per head (134 and 245 seeds, respectively) compared to the 10 t ha^{-1} rate which produced an average of 809 seeds per head. Whilst yield was not significantly affected, there was an upward yield trend of 0.5 t ha^{-1} with every 10 t ha^{-1} of mulch applied. Seed number and yield of sunflower can be substantially reduced by low radiation stress[51]. However, as these trials were conducted in the pre-monsoon and post-monsoon seasons, where incident radiation was high, this would not have been an issue. Heat stress can also reduce grain yield and quality of sunflower due to a reduction in grain size[52]. This results did not reflect this with no difference in HSW across any of the trials, indicating the most likely reason for seed number and yield decline was plant moisture stress. It can be concluded that the addition of mulch reduced moisture stress, which consequently increased seed number and yield in sunflower.

The Samlout trial exhibited no yield response to mulch, yet an increasing yield response to plant population for both crops which is most likely best explained as a consequence of near optimal growing conditions. The authors estimate that the crop was grown on a full profile of moisture, which when combined with mild daytime temperatures and cool nights, culminated in minimal plant stress and evapotranspiration losses. This could negate the above-hypothesised benefits of mulch. In contrast to the lack of grain yield response for sunflowers, plant weight did respond positively to mulch, with the 2.5 and 20 t ha^{-1} treatments producing heavier total plant weights than the 5 and 10 t ha^{-1} treatments. Even though plant biomass differed, all treatments produced identical HSW's and head diameter. However, harvest index was significantly lower for 20 than 2.5 and 10 t ha^{-1} treatments. This is probably due to minimal plant water stress during the vegetative development phase, which triggered large biomass production aiming to set high yield potentials but due to dry conditions the crop ran out of moisture and could not fulfil the high yield potential. Hence, the ratio of grain produced to plant biomass (i.e., HI) was lower than the other treatments.

Crop residue thresholds to maximise crop production: Competition exists in upland areas between crop residues as a source for animal feed and their value in providing soil cover to avoid erosion and optimise production[53,54], so through this study the authors aimed to answer the question of how much mulch or retained residue is required to maximise yield in the pre-monsoon and post-monsoon seasons. Once the optimal amounts to be retained *in situ* are established, this will clarify whether there is any surplus that could be used for cattle feed in either season. The main outcome from the pre-monsoon trial at Pailin was that 5 t ha^{-1} maize residue applied as chopped mulch to the field produced a yield of 7 t ha^{-1} which was over 100% higher than nil and 20 t ha^{-1} treatment yields.

At maturity, a maize plant has approximately equal ratios of maize stover (left *in situ*) to grain yield[55], so a rate of 5 t ha^{-1} maize residue would originate from a maize crop that also yielded 5 t ha^{-1} of grain. The average farm maize yield[56] in Northwest Cambodia in 2010 was less than this at 3.4 t ha^{-1}. Therefore, this means that farmers in this region need to implement a no till system with best agronomic management practices that include retention of all their crop residues instead of burning and ploughing, in order to optimise yield potential. The post-monsoon maize trials at Pailin further demonstrated the importance of mulch in the system with virtual crop failures in the nil treatment, yet when mulch was applied the equivalent of average monsoon district farm yields were achieved. At Pailin, the highest mulch rate of 20 t ha^{-1} provided the maximum yield for both crop types, which further supports the fact that all stover must remain *in situ* to maximise grain yield, hence suggesting there is no surplus crop stover available for cattle in either season. Farmers may need to consider incorporating forages or dual-purpose crops into their farming system to provide adequate nutrition for cattle, rather than relying on crop residues.

Impact of plant populations: Establishment of the target plant population is a widely accepted agronomic method to reduce the risk of crop failure[57] and optimise yield in variable rainfed cropping systems. For the pre-monsoon, the researchers targeted the establishment of an even plant stand of 30,000 plants ha^{-1} for maize and this is supported by other study in marginal environments[58,59] and 40,000 plants ha^{-1} for the post-monsoon. The results highlighted that maize yields were impacted by lower plant densities at either sowing time and that populations above 30,000 plants ha^{-1} were achieved by the addition of mulch and produced high yields in the variable climate of the pre-monsoon. Mean HSW in maize was highest at the 20 t ha^{-1} mulch rate, however yield and plant population were lowest in this treatment. This indicates that water was not the limiting factor during grain fill[60,61] but population density was too low to optimise yield. The reverse scenario occurred for the 5 t ha^{-1} treatment which had the lowest HSW but the highest yield and met the recommended population density target. If plant densities are too high grain size, quality and yield may be adversely affected.

At Pailin in the post-monsoon, the interaction of 20 t ha^{-1} surface applied mulch and 35,000 plants ha^{-1} produced the highest yield for maize. A population of 30-35,000 plants ha^{-1} appears to be able to withstand dry weather conditions common in both seasons, yet still produce reasonable yields without the risk of crop failure due to drought stress, resulting from too many plants competing for moisture during drought periods. Conversely to this scenario, maize at Samlout in the post-monsoon did not respond to mulch and the highest yields were attained at 65-75,000 plants ha^{-1} which was well above the target plant population of 40,000 plants ha^{-1}, probably due to high residual soil moisture and mild growing conditions.

Yield was optimised for pre-monsoon sunflower in the population range of 17-25 000 plants ha^{-1}. This result agrees with the pre-set population target for sunflower of 25,000 plants ha^{-1} for both seasons which follows recommendations for sunflower at Moree, NSW Australia under similar climatic conditions[62]. The Pailin post-monsoon trial also maximised yields at the target population density. It is surmised that low populations could not compensate enough to make up the yield deficit and at densities above 30,000 plants ha^{-1} there was insufficient moisture to sustain the population and convert biomass to grain yield.

For sunflowers at Samlout, crops with low populations suffered yield penalties due to an inability to compensate adequately for missing plants and the nil treatment was killed by spray drift so there was no control rate for comparison in the corresponding analysis. This trial did not respond to mulch rate, however there was a trend of increasing yield with increasing plant population across all treatments. The highest yield was 3.5 t ha^{-1} at a population of 50,000 plants ha^{-1}, which as previously explained was a consequence of optimal growing conditions. Although plant density was not a key factor in our hypothesis, it is an important agronomic consideration and should form part of a best management package to maximise yield.

CONCLUSION

It may not be a realistic expectation that farmers will have the resources to justify regular application of mulch in this system. However, it has been demonstrated to be a viable practice that has additional gains in increasing the sustainability of farming in this system. Similar practices, such as no-till farming and *in situ* retention of crop residues, may provide similar benefits as demonstrated here. Specifically, it appears that in a no-till system with crop stover retained and good agronomic management, a post-monsoon crop can be successfully grown on residual soil moisture. When attempting such, the farmer needs to consider that planting maize or sunflower in the post-monsoon without mulch or ground cover may result in virtual crop failure and as such would not be a feasible commercial option for farmers. In this regard, easy to assess plant characteristics such as plant height (and potentially seed number per plant) can be indicators of potential yield.

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