Research article

Effects of Crimping by Oggun Tractor-mounted Roller/crimper on Cover Crop Termination, Soil Strength, and Soil Moisture in Upland Cambodia

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Abstract Rolling/crimping technology for terminating cover crops is essential to ensure that the rolled plant residue benefits both soil and succeeding cash crops. Cambodia has also adopted this technology, but it is still at the initial stage due to limited rolling services. The objectives of this study were to compare different roller-crimpers with the Oggun-mounted USDA roller-crimper in terminating sunn hemp (*Crotalaria juncea L.)* and to determine their effects on soil strength and soil moisture. The experiment was conducted in Rattanak Mondul, Battambang province in the wet season of 2019, using a randomized complete block design with three treatments having four replicates, each of which was 14 m x 34 m and spaced 5 m. The treatments consisted of (i) a USDA roller-crimper, mounted on 19-hp Oggun tractor, (ii) a Cambodian made roller-crimper with elliptic bars, and (iii) a disc-plow, both pulled by a 75-hp tractor. Plant height and biomass before rolling; soil strength at 0-10 and 10-20 cm depths before and after rolling; field operations; and soil volumetric moisture content (VMC) evaluated on the day of rolling, and then one, two, and three weeks after rolling, along with termination rate were analyzed. The results show that the height and biomass of sunn hemp were not significantly different among the treatments, being 164 cm and 2.57 t ha^{-1}. In Oggun crimping, speed and field efficiency were lowest, being 3.5 km h^{-1} and 0.8 ha h^{-1}, but fuel use was highest. Under plow-based management, soil compaction was slightly higher and termination rate was more efficient, when compared to other treatments. Significant difference was not observed for VMC between the equipment used. However, crimping can be beneficial for cover crop termination, compared with disking that may have long-term effects on the soil.

Keywords conservation agriculture, plant biomass, sunn hemp, termination rate

INTRODUCTION

Cover crops are an integral part of conservation agriculture (CA) and are planted to benefit the soil in numerous ways (Clark, 2012). Unlike CA, conventional tillage (CT) modifies the soil, adversely affecting soil physical, chemical, and biological properties (Acar et al., 2018). Technically, CT involves plow-based practices, leaving less than 30% of crop residue on the soil surface (Vian et al., 2009). In contrast, CA is defined as a farming system whose key principles are minimal soil disturbance, permanent plant cover, and crop diversification (FAO, 2016). It helps reduce soil erosion, run-off, soil temperature, and soil compaction, retain soil moistures, increase nitrogen in the soil, and suppress weed (Balkcom et al., 2018; Mitchell et al., 2019). Because of its benefits, CA has been adopted in Cambodia since 2004 to improve soil fertility for upland crops; nevertheless, it is still considered an early stage at which rolling services remain inadequate.

There are many kinds of cover crop available in Cambodia, and sunn hemp is highly preferred. Sunn hemp (*Crotalaria juncea L.*) is a tropical leguminous crop native to India and Pakistan. It is a drought-tolerant crop that can reach 183 cm and grow on soil pH 5 to 7.5 (USDA, 2012). It produces 1 to 9 tons ha^{-1} of biomass and 122 kg ha^{-1} N in 45 to 90 days (Price et al., 2012). Seeding rates vary from 17 to 34 kg ha^{-1} (Balkcom et al., 2011). Mature sunn hemp is manageable by crimping, or herbicide, but herbicide is harmful to soil and human health (Kornecki et al., 2012).

Kornecki (2015) defined a roller-crimper as functioning to flatten cover crops on the soil surface, to kill or injure them, to create mulch through which cash crops are seeded and grow. Crimping is effective when legumes are at flowering stage, or when grass cover crops reach anthesis stages (Frasconi et. al, 2019). Cover crop termination should be done no more than three weeks before planting cash crops (Kornecki, 2009, 2012 and 2015). Crimpers consist of one or two rollers. Crimpers with one roller may have elliptic or straight bars, and the roller itself can be solid or hollow. Crimpers with one smooth roller are also common but need spontaneous operation with herbicide spray to kill the cover crop (Kornecki et al., 2012). Besides that, crimpers with two rollers use the front roller, which is usually smooth, to flatten cover crops and the rear one to crush them. Recent crimping technology is trapping and applying tractor engine heat to kill the cover crop, so the crimping mechanism is not roller-based, but like an iron (Fasconi et al., 2019).

OBJECTIVE

The objectives of this study were (1) to compare different roller-crimpers with Oggun-mounted USDA roller-crimper in terminating sunn hemp (*Crotalaria juncea* L.) and (2) to determine their effects on soil strength and soil moisture.

METHODOLOGY

In the wet season of 2019, the experiment was conducted on clayey soil, called *Mollisol*, with pH 7 to 7.13 in Rattanak Mondul District, Battambang Province, Cambodia. The average day-time temperature and monthly rainfall were 29°C and 148.6 mm (Climate.data.org, 2019). Sunn hemp was planted on May 12, 2019 at equal rate of 22 kg h^{-1} and terminated at the blossom stage.

Materials

The roller-crimpers tested in this experiment were a patented two-stage roller-crimper developed at the National Soil Dynamics Laboratory (NSDL), the United State Department of Agriculture (USDA), and a Cambodian made roller-crimper with elliptic bars. The USDA roller-crimper (Kornecki, 2011) had two drums with a width of 1.35 m. The first drum was smooth and the second drum had six straight crimping bars used. The Cambodian made roller-crimper had one roller a width of 2.0 m. designed its elliptic crimping bars. A disc-plow had six discs and was 2.0 m. long, functioning to cut and incorporate the cover crop into the soil, and turn over the soil. In addition, the tractors utilized to pull these implements were different. The USDA roller-crimper was mounted on the Oggun tractor; the Cambodian made roller-crimper and the disc-plow on a Ford 6600 tractor. Oggun is manufactured as an open-system tractor by the Cleber LLC located in Alabama, USA. It is hydraulically operated, weighs 0.8 ton, and has a 19-hp gasoline engine. The Ford 6600 tractor is powered by a 75-hp diesel engine, weighing 2.56 tons.

Design and Sampling Methods

Research design was based on the studies by Kornecki (2009, 2012 and 2015), but slightly modified to suit the Cambodian condition. A randomized complete block design (RCBD) was used comprising three treatments, each with four replications. Each plot was 34 m long and 14 m wide to accommodate at least five times the roller-crimper's widths and spaced 5 m for tractor turning. The three implements were evaluated on the same day. Before rolling, sunn hemp height was measured at 9 randomly chosen locations in each plot. Sunn hemp biomass was collected from three locations within each plot area using a 1.0-m^2 area wire frame (1.0 x 1.0 m). The biomass samples were dried for 15 days at 50 to 65°C using a solar dryer parabola dome. Before and after rolling, bulk density and soil penetration resistance were evaluated at 0-10 and 10-20 cm depths from three locations within each plot. The soil samples were dried for 24 hours at 105°C using an oven (Universal Oven UN55 Memmert). Soil penetration resistance was evaluated using a cone penetrometer with 0-100 reading scales (model S086 proving ring penetrometer). Termination rate was evaluated 7, 14, and 21 days after rolling, using a visual method. Each rolled, or disked plot was split into five and evaluated based on 0-100% scales for mortality rate. However, the rolled residue was sprayed with glyphosate two weeks after rolling, to plant corn. Due to herbicide effects, data were collected only two weeks and then averaged. Volumetric soil moisture content (VMC) was measured using a portable TDR moisture meter with 12 cm long rods (Spectrum Technologies, Plainfield, IL) on the rolling day and then 7, 14, and 21 days after rolling in each plot.

The data were analyzed performing analysis of variance (ANOVA) by using the R-software 6.3.1 available online. Fisher's protected LSD test at $\alpha = 0.05$ probability level was used to show significant difference and to determine interactions between treatment means, periods before and after rolling, and soil depths.

Fig. 1 (a) USDA roller-crimper, mounted on Oggun; (b) Cambodian made roller-crimper, pulled by 75-hp diesel tractor; (c) disc-plow with six discs

RESULTS AND DISCUSSION

Sunn Hemp Height and Biomass

Significant differences in the plant height (*P-value = 0.462*) and biomass (*P-value = 0.823*) were not observed among the treatments, being 164 cm and 2.57 t ha^{-1}. The reason was that sunn hemp was planted using the same method, but crimping/disking was applied afterwards at blossom. The plant height of sunn hemp in this study was acceptable, compared to the data by USDA (2012) and Balkcom and Reeves (2004), indicating it within the range of 120 to 180 cm. However, the plant biomass was slightly low, compared to the average value of 5.6 Mg ha^{-1}, due to prolonged drought. Balkcom et al. (2011) recognized the weather as the main factor. His findings showed that the plant biomass was even lower than 2.0 Mg ha^{-1} despite different planting dates and seed rates applied.

Field Operations

There were significant differences in speed, fuel consumption, and field efficiency (*P-value < 0.001*) among the treatments. Disking speed was the fastest, operated at 5.21 km h^{-1}, followed by the Cambodian made roller-crimper at 4.5 km h^{-1} and the USDA roller-crimper at 3.5 km h^{-1}. The Oggun consumed 21.35 liter ha^{-1}, greater than the 75-hp tractor that used 11.13 liter ha^{-1} for disking and 12.44 liter ha^{-1} for crimping. Oggun crimping achieved low field efficiency at 0.79 ha h^{-1}, while disking and crimping with elliptic bars accomplished more work, equal to 1.10 and 1.27 ha h^{-1}. Low Oggun performance is most likely associated with the engine size, weight, attached equipment, rolling method and land condition. Likewise, Kornecki et al. (2009 and 2015) studied greater speed and attributed the field efficiency to speed and numbers of rolling passages.

Table 1 Sunn hemp height, biomass, and field operations by crimping/disking

Treatment	Plant height (cm)	Plant biomass (t ha^{-1})	Speed (km h^{-1})	Fuel use (l ha^{-1})	Field efficiency (ha h^{-1})
USDA-crimper	166.42 a	2.50 a	3.50 c	21.35 c	0.79 c
Cambodian crimper	167.42 a	2.66 a	4.50 b	12.44 b	1.09 b
Tillage	159.75 a	2.54 a	5.21 c	11.14 a	1.27 a
SE	6.628	0.260	0.269	1.030	0.092
CV (%)	9.87	24.8	14.96	13.75	9.95
T-test probability	0.462	0.823	<0.001***	<0.001***	<0.001***

**** significant at p < 0.001 and letters in the same column refer to the difference between treatments.*

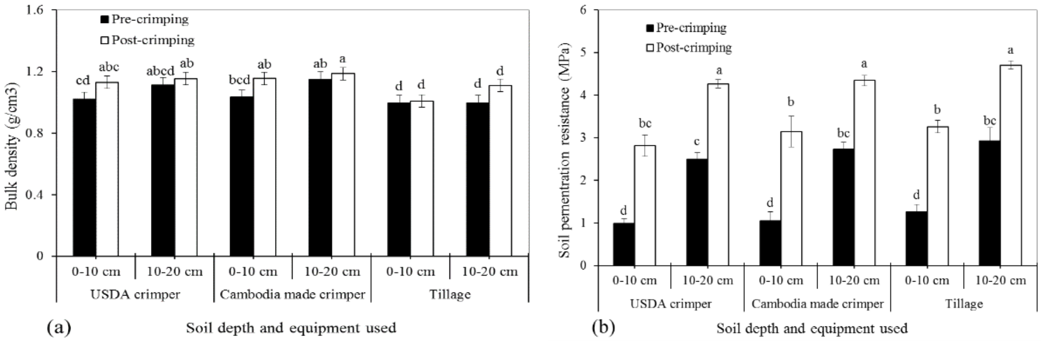

Fig. 2 Bulk density and soil penetration resistance (mean± SD) examined at different depths before and after rolling, with respect to the equipment used. Means with different letters are significantly different (LSD-Test, p < 0.05)

Bulk Density

Bulk density was examined at 0-10 and 10-20 cm depths, and then compared before and after rolling. No significant interactions between the equipment used and soil depth in both periods (*P-value = 0.265*). However, significant differences were observed among the treatments with respect to depths and rolling periods (*P-value = 0.043*). After rolling, bulk density increased by 0.1 to 0.2 g cm^{-3}. In disking, no significant difference was found since the soil became loose, when disked and turned over at less than 30 cm depth. Higher bulk density was observed at deeper subsoils, regardless of the equipment used. In this study, bulk density averaged 1.2 g cm^{-3}, which was categorized by Rowell (1994) and Duruaha et al. (2007) as little impacts on plant root development.

Soil Penetration Resistance

No significant interactions between the equipment and soil depth were observed in both periods (*P-value = 0.917*). Although crimping/disking was not applied, soil compaction still increased as soil depth increased (*P-value < 0.001*). Soil compaction was even greater after utilizing the equipment (*P-value = 0.025*), indicating the effects of the equipment on the soil. Before rolling, soil penetration resistance measured at the 0-10 cm depth was similar in all treatments, being approximately 1.1 MPa, but increased to 3 MPa after rolling. At the 10-20 cm depth, soil compaction became greater when crimping/disking was applied, but was not significantly different among the equipment used. As a result, it increased from 2.7 MPa before rolling to 4.4 MPa after rolling. These values fell into the range that Bartzen et al. (2019) classified as medium limitations on plant root growth, but exceeded the threshold value of 2 MPa, that might restrict corn root elongation (Unger et al., 1994).

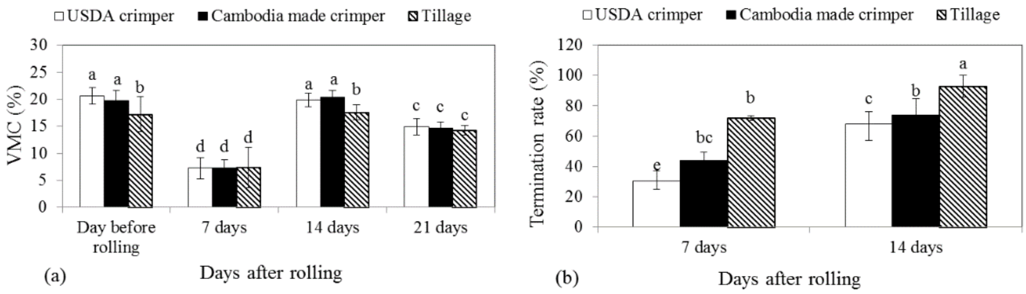

Fig. 3 Effects of crimping/disking on soil volumetric moisture content (VMC) and sunn hemp termination rate (mean % ± SD) evaluated with respect to time. Means with different letters are significantly different (LSD-Test, p < 0.05)

Volumetric Soil Moisture Content (VMC)

Soil moisture was examined on the day before rolling and after first, second, and third week, with respect to the equipment (Fig. 3). There were significant interactions between treatments and weeks ($P < 0.001$); thus, the data were analyzed weekly. On the day before rolling, significant differences in VMC were observed among the treatments ($P < 0.001$), being 21.6% in Oggun crimping, 19.8% in crimping elliptic bars, and 17.2% in disking. One week after rolling, no significant differences were detected ($P < 0.525$) and VMC averaged 7.3%. In week two, there were significant differences in VMC ($P < 0.001$), being 20.1% in both crimping types and 17.6% in disking. However, VMC were not significantly different in week three ($P < 0.188$), measured at 14.7%. It was observed that VMC fluctuated over time, but a sharp decrease in VMC was observed in week one after cover crop termination, due to sunn hemp decomposition that could not prevent water losses. In weeks two and three, VMC increased because of successive rains that replenished the soil with water. With respect to the equipment used, Effects of soil water losses caused by disking were not clearly seen due to the interference of rainfalls and low cover crop biomass production.

Sunn Hemp Termination

Mechanical termination was evaluated, analyzed and compared in two weeks only. There were significant interactions between treatments and weeks ($p < 0.001$); thus, the data were compared by week. In both weeks, significant differences in sunn hemp termination rate were observed among the treatments ($p < 0.001$). In week one, termination rates for oggun crimping, crimping with elliptic bars, and disking were 30.5, 44.1, and 71.5%, respectively. The value increased sharply in week two, but remained significantly lower in Oggun crimping, compared to operation by the 75-hp tractor. In that week, Oggun crimping obtained the termination rate at 67.8%, tractor crimping at 74%, and disking at 92.9%. Highest termination rate was found in disking because sunn hemp was subject to damage, when cut, crushed and buried in the soil. The termination rate obtained in this study were lower than the recommendations by Kornecki (2015), reporting that achieving 90% in two weeks is critical for succeeding cash crops and profitable.

CONCLUSION

Two different roller-crimpers were compared with disking in terminating sunn hemp in upland Cambodia. The USDA roller-crimper consumed more fuel amounts but had lower field efficiency, when compared to other treatments. Termination rate by Oggun crimping was also lower than 75-hp tractor operations. Tractor weight, engine size, rolling method, and soil condition tend to be the main cause. Bulk density, soil penetration resistance, and VMC in all treatments seem not to be different. Despite that, it can be observed that the disked plots had disturbed soil with less crop residue, leaving it exposed to the sun and prone to moisture losses, when compared with crimping.

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REFERENCES

Acar, M., Celik, I. and Günal, H. 2018. Effects of long-term tillage systems on aggregate-associated organic carbon in the eastern mediterranean region of Turkey. Eurasian Journal of Science, (1), 51-58.

Balkcom, K.S. and Reeves, D.W. 2004. Sunn-Hemp utilized as a legume cover crop for corn production. American Soiciety of Agronomy, Agron. J., 97, 26-31.

Balkcom, K.S., Kornecki, T.S. and Price, A.J. 2018. A simple guide for conservation systems in the southeast Auburn, AL. United States Department of Agriculture, Agricultural Research Service, National Soil Dynamics Laboratory Conservation Systems Resesarch.

Balkcom, K.S., Massey, J.M., Mosjidis, J.A., Price, A.J. and Enloe, S.F. 2011. Planting date and seeding rate effects on sunn hemp biomass and nitrogen production for a winter cover crop. Hindawi Publishing Cooporation, International Journal of Agronomy, doi:10.1155/2011/237510.

Bartzen, B.T., Hoelscher, G.L., Ribeiro, L.L.O. and Seidel, E.P. 2019. How the soil resistance to penetration affects the development of agricultural crops? Journal of Experimental Agriculture International, 30 (5), 1-17.

Clark, A. 2012. Managing cover crops profitably (3rd Ed.). College Park, MD, Sustainable Agriculture Research and Education.

Climate.data.org. 2019. Climate Battabang. Retrieved 11 05, 2019, Retrived from https://en.climate-data.org /asia/cambodia/battambang/battambang-3145/

Duruoha, C., Piffer, C.R. and Silva, P.A. 2007. Corn root length density and root diameter as affected by soil compaction and soil water content. Irriga, Botucatu, 12 (1), 14-26. ISSN 1808-3765.

FAO. 2016. Conservation agriculture. Retrieved from Food and Agriculture Organization of the United States : http://www.fao.org/3/a-i7480e.pdf

Frasconi, C., Martelloni, L., Antichi, D., Raffaelli, M., Fontanelli, M., Peruzzi, A., Benincasa, P. and Tosti, G. 2019. Combining roller crimpers and flaming for termination of cover crops in herbicide-free no-till cropping systems. PLOS ONE, 1-19.

Korneck, T.S. 2011. Multistage crop roller. U.S. Patent# 7.987.917 B1. August 02, 2011.

Kornecki, T.S. 2015. Rye termination by different rollers / crimpers developed for no-till small-scale farms. American Society of Agricultural and Biological Engineering, 31 (6), 849-856.

Kornecki, T.S., Arriaga, F.J. and Price, A.J. 2012. Roller type and operating speed effects on rye termination rates, soil moisture, and yield of sweet corn in a no-till system. HortScience, 47 (2), 217-223.

Kornecki, T.S., Price, A.J., Raper, R.L. and Arriaga, F.J. 2009. New roller crimper concepts for mechanical termincation of cover crops in conservation agriculture. Renewable Agriculture and Food Systems, 24 (3), 165-173. doi: 10.1017/S1742175009002580.

Mitchell, J.P., Reicosky, D.C., Kueneman, E.A., Fisher, J. and Beck, D. 2018. Conservation agriculture systems. CAB Reviews, doi: 10.1079/PAVSNNR201914001.

Price, A.J., Kelto, J. and Mosjidis, J. 2012. Utilization of sunn hemp for cover crops and weed control in temperate climates. Rijeka, Croatia: InTech Europe, University Campus STeP Ri.

Rowell, D.L. 1994. Soil science methods & applications. Longman Group UK Limited., New York.

Unger, P.W. and Kaspar, T.C. 1994. Soil Compaction and Root Growth: A Review. Agronomy journal, 759-765.

United States Department of Agriculture. 2012. Plant guide: Sunn hemp *(Crotalaria juncea* L.*)*. Cape May, NJ. 08210: USDA-Natural Resources Conservation Service, Cape May Plant Materials Center.

Vian, J.F., Peigne, J., Chaussod, R. and Roger-Estrade, J. 2009. Effects of four tillage systems on soil structure and soil microbial biomass in organic farming. Soil Use and Management, 25, 1-10.