UTILIZATION OF RICE STRAW IN THE WORLD AND IN VIETNAM

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ABSTRACT

This paper reviews the utilization of rice straw in the world, including the production and properties of straw, different equipment for gathering and processing of straw as related to the costs in handling operations, and various methods of using straw - from simple ways such as cattle feeding or organic fertilizers, to more complicated ways such as using starw in electrical power generation or paper industry. Straw utilization in Vietnam is presented in parallel, with emphasis on identifying problems to be studied and verified versus other results in the world.

Keywords: *rice straw; straw equipment; baler; straw utilization; Vietnam.*

TÓM TẮT

Bài viết tổng hợp về sử dụng rơm lúa trên thế giới, bao gồm sản lượng và tính chất rơm, các thiết bị thu gom và chế biến rơm, chi phí liên quan đến các công đoạn này, các phương pháp sử dụng rơm lúa -từ các cách đơn giản như cho trâu bò ăn hoặc làm phân hữu cơ, đến các phương thức phức tạp hơn như dùng rơm để phát điện hay cho công nghiệp giấy. Song song trình bày việc sử dụng rơm ở Việt Nam, nhấn mạnh đến các vấn đề cần nghiên cứu và kiểm chứng đối chiếu với các kết quả trên thế giới.

Từ khóa: *rơm lúa; thiết bị xử lí rơm; máy cuốn rơm; sử dụng rơm; Việt Nam.*

INTRODUCTION

In 2015 the world produced over 700 million tons (Mt) of paddy, of which 41 Mt from Vietnam (GSO 2015); with a quantity of straw as about equal to that of grain. Straw once was considered as a residue or waste from rice, thus was incorporated or burned in the field, or was just used a little for cattle feeding. Later, straw is supplied for different processes, such as mushroom production, building materials, or for power generation. The rice post-harvest technology is no longer limited in paddy and milled rice, since now there is a triangle of *Paddy-Milled Rice-Straw*. In Vietnam, from 2012 to 2013, the National Extension Center and three collaboration Projects have dealt with rice residues including straw, namely: 1/ SNV Project of Netherlands at Quang Binh and Binh Dinh provinces (Phan Hieu Hien and Nguyen Thanh Nghi, 2013); 2/ IRRI (International Rice Research Institute) in collaboration with Nong-Lam University (NLU) by (Nguyen Thanh Nghi et al, 2015); 3/ Pitea City of Sweden with An Giang Province (An Giang Sweden Project 2014).

This paper reviews the utilization of rice straw in the world and comparatively in Vietnam, including the available harvested quantity and properties of straw, description of different equipment for gathering and processing of straw related to the costs in handling operations, straw storage, and utilization of rice straw - from field burning and cattle feeding to electrical power generation, etc. Straw utilization in Vietnam is presented with emphasis on identifying specific problems to be studied and verified versus other results in the world.

YIELD AND PROPERTIES OF RICE STRAW

Data below was from a study of Summers et al. (2001) on 8 rice varieties in California: Straw yield was 7.0-13.6 t/ha and 9.8 t /ha on average. Straw/Grain Ratio (dry mass) was 0.89-2.3 with 1.27 on average.

The percentage of stubble left in the field varies in cutting heigtht (Figure 1). At 0.35m cutting heigtht, only 50% of straw is gathered while the other half remains as stubble on field.

The chemical analysis of straw is shown in Table 1.

Table 1. Ultimate analysis and proximate analysis (% dry basis) of rice straw in California

	C, %	H, %	O, %	N, %	S, %	Cl, %	Si & other	HHV, MJ/kg
Fresh straw	41.68	4.63	36.57	0.70	0.08	0.34	16.0	16.3
Weathered straw	34.60	3.93	35.38	0.93	0.16		25.0	14.56

Source: Kitani, 1999

Fixed Carbon, %	Volatile, %	Ash, %
15.86	65.47	18.67

Source: Summers et al., 2001

Note the un-even distribution: about half of the biomass is at the lower third of the plant; 62% is in the leaf and sheath, only 38% is in the stem and panicle (not including grain). Silica takes 15% in the leaf, but only 5% in the stem.

Table 2 shows the chemical elements in the rice straw (Rosmiza et al., 2014). Straw does not have much N, P, K but it supplies a great deal of organic matter from about 40% C, and several oligo-elements needed for the plant, such as S, Mg, Mn, etc.

Table 2. Percentage of chemical elements in rice straw %

Chemincal elements	Percentage (%)
N	0.65
P	0.10
K	1.40
Zn	0.003
S	0.075
Si	5.50
Mg	0.20
Ca	0.30
Fe	0.035
Mn	0.045
Cu	0.0003
B	0.0010

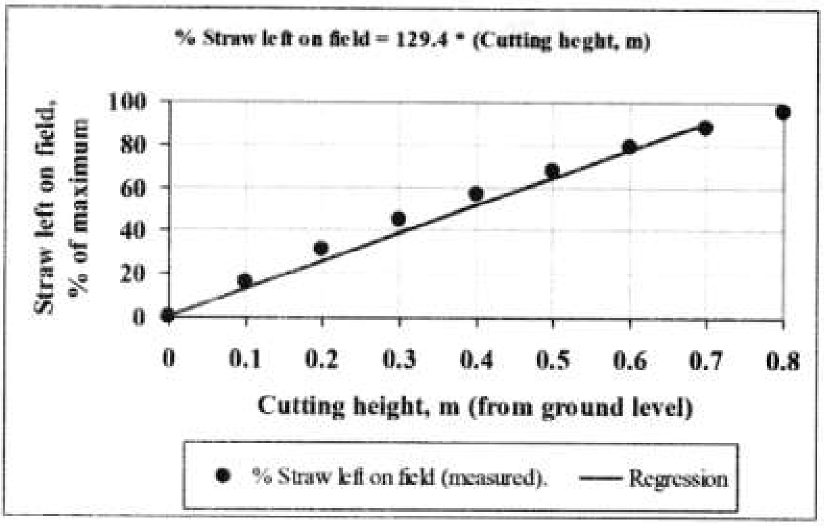

Figure 1. The percentage of stubble remained in the field varies with the cutting height. (Summers et al., 2001)

To estimate the harvested straw or available cut straw, a Straw/Grain Ratio of 1.0 (by weight) is generally assumed with the cutting height at the ground level, even that the ratio varies slightly with varieties. As the cutting height increases, the Cut Straw/Grain ratio decreases as the left stubble increases. Figure 1 shows these relationships with data from 8 varieties in California; no similar data is available in Asia. In Vietnam, a study for FAO (Phan Hieu Hien, 2009) estimated the cut straw was 21.5 Mt; this was based on the paddy production of 36 Mt in 2007, and rice plants at a cutting height between 0.2 m and 0.3 m, meaning a Cut Straw / Grain of 0.60, or 40% of the residue was left as stubble. In 2014, paddy production increased to 45 Mt, thus the corresponding estimated straw quantity was 27 Mt.

In China, the rice straw was 186 Mt in 2008 compared to 226 Mt of corn stover and 116 Mt of wheat straw (Hu, 2011). Note that the estimate was based on a high Cut Straw/Grain ratio of 0.97.

Thus the available straw depends on the specific year and the estimated Cut Straw/Grain ratio.

EQUIPMENT FOR GATHERING AND PROCESSING OF STRAW

Instead of field burning, straw can be gathered mainly by two types of balers besides some other loose-straw gatherers. Straw balers can be divided in terms of the bale's bulk density:

Low: < 100 kg/m^3, applied for wet straw of about 40% moisture content (MC). Bales later should be dried for storage. Drying by forced aeration of wet straw yields more nutritional value than sun drying in the field; for example, protein content is 50% higher (Klenin et al., 1985). The data should be verified under the conditions of Vietnam.

Medium: 100- 200 kg/m^3, applied for straw with MC not exceeding 25%.

High: > 300 kg/m^3, applied for straw with MC under 20%. Evidently at this MC, different bulk density from baling can be obtained. The power for baling is the lowest for straw at 18- 25% MC; too dry straw (MC under 13%) increases the power consumption for baling.

Cubic-bale straw baler

Straw is baled into rectangular cubes. Large units, such as the *Hesston-4800* baler in the *USA* (Figure 2) produce bales that are 2.5 m long, 1.2 m wide, and 1.2 m high, weighing 870 kg with straw at 14% MC, and bulk density of 240 kg/m^3. Baling capacity is 10 t/hr. A tractor with two trailers can carry 28 m^3 of straw, which is equivalent to 19 - 25 tons depending on the MC. The loading and unloading time onto and out of the trailers are 52 and 15 minutes respectively (Jenkins et al., 1985). This baler model was first produced in 1978, underwent modifications and 25, 000 units were sold up to 2007 (Sorensen, 2013).

Figure 2. *Hesston 4800* cubic-bale straw baler

Figure 3. Cubic-bale straw balers fabricated by Z755 Factory in the 1990's

Vietnam in the 1970's had cubic-bale straw balers and used for the paper mills in Dong Nai Province. The fabrication of these balers resumed in the 1990's by Z755, a military mechanical factory (Figure 3) but stopped afer a decade when the Mekong Delta shifted to the combine-harvester, because stationary balers need straw from stationary threshers, wherein paddy and straw are gathered to fixed places, not scattered throughout the field.

Round-bale straw baler

In the USA and Europe large baler are used; for example, bales are Φ 1,67 m x 1,67 m height, weight 360 kg (Dobie et al., 1977), and have bulk density of 100 kg/m^3 with dry straw (Figure 4).

Figure 4. A large–size baler (360-kg bales) with bucket and rake in front for loading bales into the trailer.

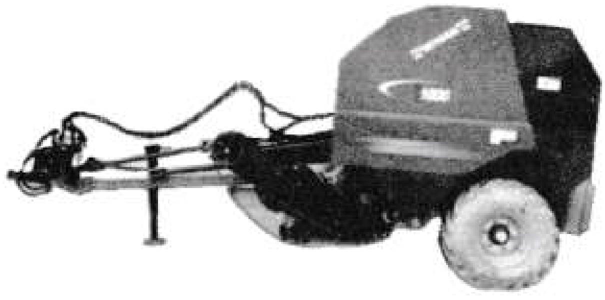

Figure 5. A pulled-behind-tractor baler for 420-kg bales

Another brand (Figure 5) gives out bales that are Φ 1,1 m x 0,95 m height, weight 424 kg, and have bulk density of 470 kg/m^3 (Chang et al., 2012). Test of this balers in *Korea* in conjunction with a 47-kW tractor indicates that the baling power varies, averaging form 15.1 kW to a maximum of 31.4 kW.

Working parts of a baler include: straw pick-up gatherer, straw baling component which can be either forming belts (Figure 6) or steel rollers (Figure 7), straw ejector, and knotter (Figure 8),

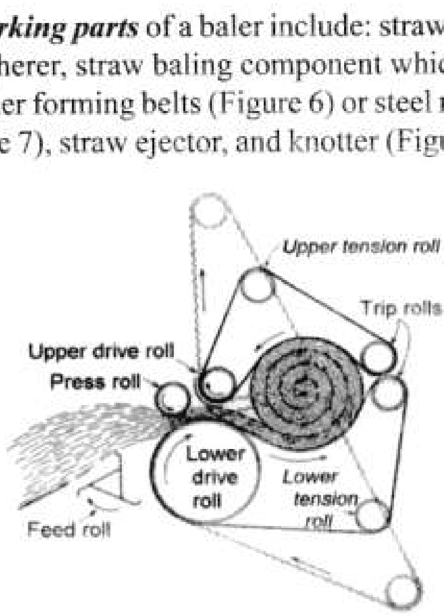

Figure 6. Schematic of forming belts for round balers (Richey et al., 1960)

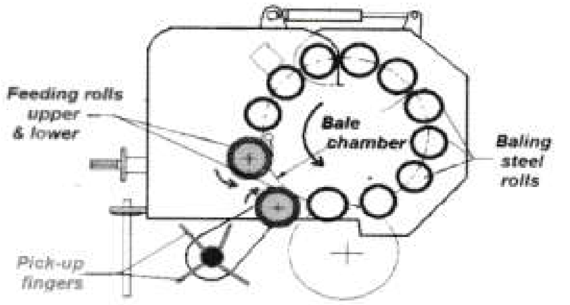

Figure 7. Forming steel rollers for round bales (Wang et al., 2011)

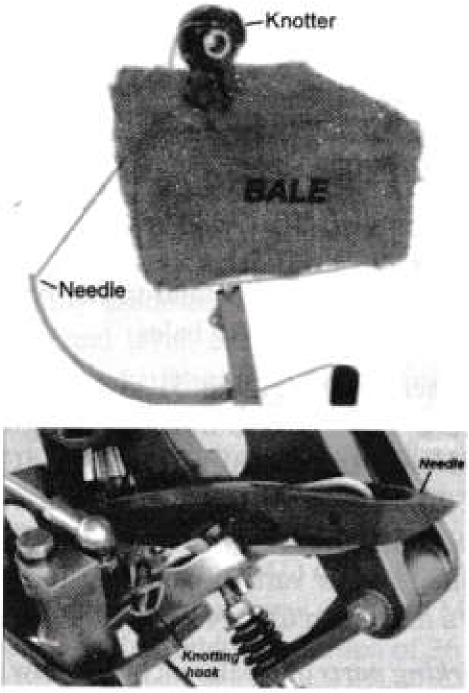

Figure 8. Knotter for balers

(Source: Claas, 2015)

In China, development of straw harvesting machinery started around 2000, together with imported models from Claas, John Deere, etc. Until 2006, there were about 1000 small balers (bale mass 15 - 20 kg), which only handled less than 1% of the straw amount in the country. From then, faster development took place with a dozen of baler manufacturers. In parallel, straw chopper-spreaders for returning straw to the field increased rapidly with 591 000 units in 2007; which was a 25% increase compared to 2005 (Han, 2003; Hu et al., 2011).

In Vietnam, current balers produce small bales that are Φ 0,5 m x 0,7 m height or Φ 0,45 m x 0,75 m height and have bulk density of about 100 kg/m^3 from "dry" straw at 15% MC; however, with very wet straw of ≈70% MC, each bale is heavier than 50 kg, which means bale density is more than 300 kg/m^3.

In 2016, a Seminar and Demonstration on "*Equipment and technology for gathering and treatment of rice straw*" was jointly organized in Can Tho City by the Vietnamese National Extension, Nong Lam University, and IRRI. Central and Provincial authorities contributed 30 papers to the Seminar. Six manufacturers and dealers of imported models participated in the demonstration. Measurements were taken on 4 balers on a typical field with 4.6 tons of straw/hectare; preliminary results are summarized in Table 3 (Phan Hieu Hien et al., 2016).

Table 3. Performance of 4 rice straw balers in Can Tho City, 2016

Bale mass, kg, Ave±StDev	Bale density kg/m^3	Field capacity ha/ hr	Field capacity t/ hr	Un-gathered % (loss)	(Calculated) Man-hrs/ ton
12.8 ± 1.2	87 ± 9.1	0.46 ± 0.11	1.60 ± 0.55	26 ± 11	1.82 ± 0.72

Note: Labors on machine: 01 for a self-propelled unit; 02 for a pulled-behind tractor unit. Labors for bale collecting: none for a self-propelled unit; 03 for a pulled-behind tractor unit.

Later in 2017, two models are widely commercialized with specifications listed in Table 4.

• Galan-STAR MRB0855 baler (imported) is semi-mounted behind a tractor of 20 HP minimum (Figure 9). This baler is low-cost (Table 4) because it uses existing tractors; but it ejects bales over the field, thus need addtional labors for collecting and transporting bales to the field border. Moreover, as the tractor leads the way, bales are mud-dirty in muddy fields.

• Phan Tan PT-CR57 baler (fabricated in Dong Thap province) is self-propelled on rubber tracklayers, with a platform containing about 30 bales (Figure 10). The PT-CR57 costs much more, but since it is self-propelled and dumps bales onto the field border, this unit saves labor. In muddy fields, the bales are clean since the baling component is at the front line.

Table 4. Specifications of two balers and their prices as quoted by the manufacturer/ dealer

Model	Overall dimensions (L*W*H), mm	Weight, kG	Engine power, HP	Bale, dia Φ * long, mm	List price, USD
STAR MRB0855	1150*1300*1300 (without tractor)	340	tractor > 20	500 * 700	6 200
PT-CR57	4500*2250*2450 (self-propelled)	1 800	45	500 * 700	13 000

Note: *(#): Prices converted at 1 USD = 22 000 Vietnamese dong (VND) (in March 2016).*

Figure 9. (a) Galan-IHI STAR MRB0855 baler behind a 30-HP tractor

Figure 10.
(a) Phan Tan CR57 baler (b) Bales dumped from CR57 platform onto the field border

Other straw collecting equipments

In the 1970s, the USA had a raking equipment which pushed straw into piles at the field border, and straw was either ground or baled. The straw pile was loose with a bulk density of 30- 50 kg/m^3; transportation cost was high and large storage space was needed. Therefore, this method is no longer applied.

In 2014, Phan Tan company in Dong Thap province of Vietnam fabricated the *straw bulldozer*. The machine pushes straw along into a collecting place. However, this model with just a few customers was not popular.

In 2015, Hai Tinh workshop in An Giang province fabricated the *straw collector*. Straw is raked in the same way as a baler, but there is no baling component (Figure 11). Loose straw is conveyed to a trailer which leads to bulky piles of straw.

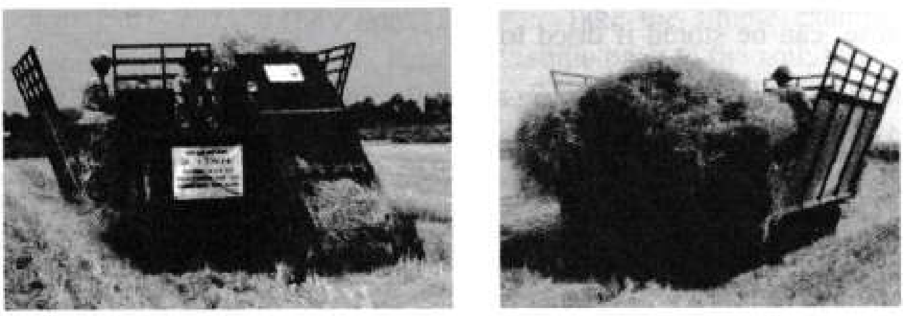

Figure 11. The Hai Tinh straw collector, front and rear views.

Problems related to the use of combine-harvesters (CBH) and straw balers.

The CBH usually operates at cutting heights of 0.4-0.45 m for efficiency, meaning high capacity, good grain separation, and clean grain. Low cutting height (0.2-0.3 m) is only in harvesting lodged crop.

On the other hand, as shown in Figure 1, at the usual cutting height, only 40% of the straw can be collected, the remaining 60% is "stubble" rooted in the field. Thus the CBH and the straw baler work against each other in terms of economic return. Therefore, research is needed in Vietnam on the effect of cutting height on the trade-off between these two equipment.

Straw storage

Straw is not used right after collecting, thus it needs storage. Wet straw is just suitable in making silage for cattle or producing biogas, which means for short-term uses.

Warehouses for storage are suitable for compressed bales, either with cubic rectangular (bulk density 130- 145 kg/m^3) or round (bulk density 100- 110 kg/m^3) shapes. Bales take up less space (Dobie, 1977), only 2.0-2.4 m^2/ton for cubic bales, and 2.4-2.8 m^2/ton for round bales.

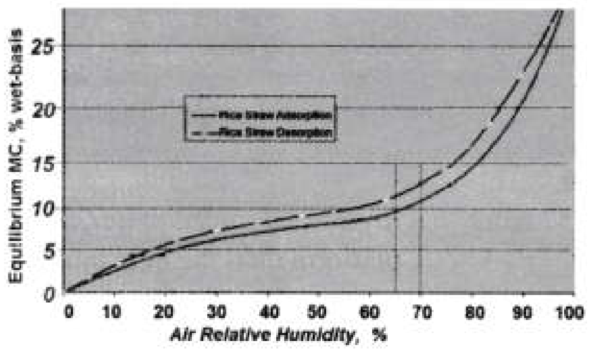

Figure 12. The equilibrium MC of rice straw at 25 °C. (Thompson 1974)

A shed shelter or tapaulin to cover the bale pile is needed, especially on several layers of bales. Because water from a heavy rain might penetrate as deep as 0.15 m into the surface layer and infiltrate into lower layers to decompose the straw.

Straw, like other organic materials containing cellulose, can be stored if dried to the equilibrium moisture content (EMC) with the air relative humidity of about 70%. Thus, considering the EMC chart (Figure 12) with weather temperatures of the Mekong Delta in the range of 24-33 °C, the straw should be dried to about 13% (wet basis) for storage.

Straw harvested during rainy seasons in the Mekong Delta is either very wet or submerged in water, with MC of 50% or more, thus could not store for one week. If dried down to 13% by conventional heated-air drying, the cost would be too high compared to the straw value. Maybe the aeration drying is appropriate because it uses a minimum airflow with ambient un-heated air to save energy; the drying time may last several days before the straw EMC is reached. This is another topic to be verified under weather conditions of the Mekong Delta.

COSTS OF BALING AND TRANSPORT OF RICE STRAW

In 1975, research on the baling costs in the USA with equipments shown in Figure 4 (Dobie et al., 1977) is summarized in Table 5. For easy comparison, the following conversion rates are used:

1 USD in 1975 = 3,5 USD in 2015 (Source: http://stats.areppim.com/calc/calc_usdlrxdeflator.php).

1 USD in 2015 ≈ 22 000 VND in 2015,

So: 1 USD in 1975 (USD_{1975}) = 3.5 *22000 = 77000 VND_{2015}.

Table 5. Costs of straw baling and collecting in California in 1975 (converted to USD_{2015} and VND_{2015}). *Baler with tractor PTO-driven, bales of 360 kg, Field capacity 5.4 ton/hr (bales dropped on field).*

a) Fixed cost		USD_{2015}	VND_{2015}
Equipment purchase price, 7595 USD_{1975}		26 600	585 million VND
	(Equipment life: 6 years)	(2500 hrs)	(2500 hrs)
Costs of depreciation & interest @ 8% /year		5 690	125 million VND
b) Total operating costs per ton		*16.49*	*362 800*
c) Total cost per ton of straw bale			
for 2200 ton annual capacity:	Fixed cost	2.63	57 800
	Operating cost	16.49	362 700
	Total cost per ton	19.11	420 500

d) Cost of collecting bales to the field border/ton	12.95	284900
e) Total cost (baling & collecting) = c + d =	32.06	705 400
f) Transport to the site (16 km away)	64.30	1 414 500
Grand total = e + f =	96.36	2 119 800

Note: Transport cost per (ton. km) = 0.245 USD_{1975} = 0.86 USD_{2015} = 18 800 VND_{2015}.

Table 6. Straw collecting costs at two sites in the Mekong Delta of Vietnam (2015)

Owner (coded):	5A (Tien Giang)	6D (An Giang)	Note N#
a) Collecting cost on field	VND /bale	VND /bale	
Straw purchase (to farmer)	5 000	1 000	N#1
Labor (driver)	1 000	1 000	
Twine for knotting	1 000	1 000	
Diesel fuel	1 000	700	N#2&#3
Total (for each bale):	8 000	3 500	
b) Labor (transport to the boat)	5 000	5 000	N#4
c) Total /bale = a) + b) =	13 000	8 500	
The bale mass =	15 kg	13 kg	
=> Cost of collecting 1 ton of straw:	867 000 VND = *39.41 USD*	654 000 VND = *29.73 USD*	

Note: *N#1: In Tien Giang, straw purchase is 600 000 VND/ha, yielding 120 bales.*

In An Giang, straw is much cheaper because baling equipment is not common.

N#2: Self-propelled baler, 60 HP. N#3: Baler is pulled behind a 30-HP tractor, 9 liter/day.

N#4: Labor for carrying bales from field borders to boats at river bank. Labor rate is cheaper in An Giang, thus compensates for additional transport from inside the field to field border.

Table 5 shows that the on-field baling cost is only 1/3 of the total cost; the other 2/3 is transport cost, even with only 16 km. Thus for any scheme, the price of straw as input material should be based at the utilization site.

In Vietnam, similar published data is scarce, so we interviewed two baler owners in Tien Giang and An Giang Provinces in 2015 (Table 6).

One interesting coindidence (Table 6) is that the collecting cost in the USA (32.06 USD/t, Table 5) lied between those in Tien Giang and An Giang (39.41 and 29.73 USD/ton).

UTILIZATION OF RICE STRAW

Straw, viewed as a supply material for some business activities, should be set in its value chain. Thus straw utilization should consider its economic value in the chain, at least relating to the costs. Straw baling and collecting should aim at some specific uses from different standpoints of farmer's, trader's, and user's; baling is the third way of using straw versus two traditional ways which are burning and incorporation.

Take the simple example of incorporating straw back to the soil; how much does it cost? From a study in the 1990's in the USA (Blank et al., 1993), this cost (calculated with 2.5 t/ha) was 57 USD_{2015}/ha, as converted from 1 $USD_{1991-1992}$ = 1,58 USD_{2015}.

From Vietnam's newspaper in 2015, some local companies planned to export straw to Japan. The question is: besides foreign-currency earning, for one ton of exported straw, how much does the local soil lose in nutrients, and at what cost? A study in the USA (Blank, 1993) showed removing straw from the field did not affect the nitrogen (N), but the removed K, P, Zn, and S were valued at 4.3 $USD_{1991-1992}$, or 6.8 USD_{2015}, or 150 000 VND_{2015} per ton.

In China, utilization of straw was compiled by Hu et al. (2011). However, the major use of straw as cooking fuel (Figure 13) in rural areas has steadily decreased since 1995 and the continuing use as commercial energy supplies (oil, gas and coal) has remarkably increased. Consequently, more un-used or burned-in-field straw are expected.

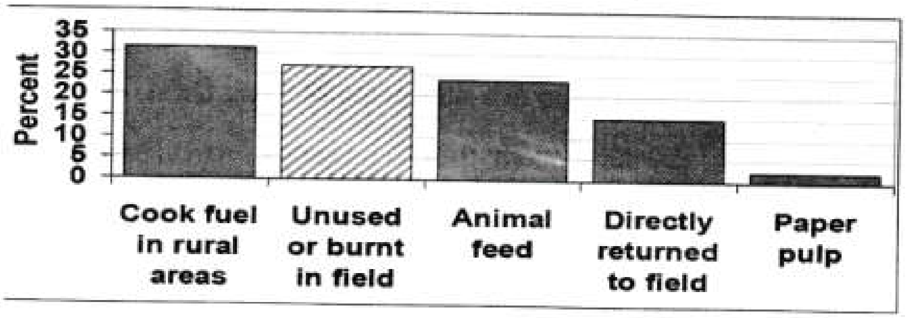

Figure 13. Utilization of (all) crop straw in China, 2008.

Field burning of straw

This is the oldest "utilization" method, and it is convenient for farmers: simple and least costy. It also has some added nutrients and timeliness of planting. But apparent consequences are emissions of CO_2 and NO_x into the atmosphere and even 20- 25% of P and K nutrients are lost upon burning.

In California, in 1991, with the Rice Straw Burning Reduction Act (Summers LLC, 2012), the field straw burning of 95% of rice area in the 1980-1990's decreased to under 10% in 2010. In the same period; straw incorporation increased from 5% to 90%, while baling rice straw only increased slightly from 0% to 3%

In Vietnam, a study at Can Tho University in the Mekong Delta in 2012 with interviews of 100 farmers in 4 provinces of An Giang, Kien Giang, Dong Thap, Can Tho (Tran Sy Nam et al., 2014). Results showed that for all rice crop seasons, more than 90% of straw was burnt in the fields; while straw for mushroom growing and cattle feeding took less than 1% each.

However, a previous study (Phan Hieu Hien, 2009) showed a more detailed picture. It calculated for provinces visited for interviews

$$SAR\ (Straw\ /\ Animal\ Ratio) = \frac{Quantity\ (tonne)\ of\ Straw\ from\ rice\ production}{Heads\ of\ Animal\ (cattle + buffalo)}$$

and related to the degree of straw field burning, which is rather "qualitative" in interviews, with steps of 20% (0, 20, 40, 60, 80, 100% field burning). Results are presented in Table 7. These results in Dong Thap and An Giang are similar to those obtained from Can-Tho University's study. For Provinces in Central Vietnam as well as Ben Tre in the Mekong Delta, the *SAR* ratio is very low, meaning straw is used for cattle feeding and no field burning occurs.

Table 7. Status of field burning of straw, as related to *SAR* in 2009

Province	*SAR*	Status
Central Vietnam		
Thanh Hoa, Nghe An, Quang Tri, Phu Yen	0.7- 1.3	No Field Burning (FB)
Mekong Delta		
Ben Tre	1.1	No FB
Tra Vinh	3.8	Less than 20% FB
Tien Giang	12.0	More than 40% FB
Dong Thap	43.3	More than 80% FB (very high *SARs*)
An Giang	23.9	

From 2014 to 2016, with the fast increase of balers (estimated at about 2000 units in 2016) and strong recommendation of not burning straw from Extension workers, burning rate has decreased appreciably. For example, Tien Giang province used to burn half of its straw (Table 7), but from 2016 not much field burning can be seen, as confirmed by several farmers, traders, extension workers, etc. that the author interviewed as well as from his own observations.

Field incorporation of straw

California in 2010 has 90% of its rice area with straw incorporation on field. Returning organic matters back to the field is clearly seen in the region, although its modern agriculture is using quite a lot of inorganic fertilizers. Twenty-two methods and equipment (flail chopper, disc plow, cagewheel, etc.) were documented; Table 8 shows some typical results (Blank et al., 1993). Apparently, straw incorporation costs 5-18 times compared to field burning. However, it brings several advantages such as improving the soil fertility and stabilizing the rice yield in spite of continuous rice cultivation, thus compensates for the added costs.

Table 8. Cost comparison of different incorporation methods versus field burning of straw

Methods	USD_{1991} /acre	USD_{2015}/ha	VND_{2015}/ha	Cost Ratio to burning
Chopped with flail mower	12.74	50.32	1110 000	15.5
Stubble disc 4,2 m (first pass)	8.54	33.73	740 000	12.3
Finishing disc 6,3 m (2nd pass)	6.14	24.25	530 000	8.8
Cagewheel roller	3.71	14.65	320 000	5.3
Field burning (average)	0.67	2.66	60 000	1.0

Note: Conversion rates: 1 $USD_{1991-1992}$ = 1.58 USD_{2015}, and 1 USD_{2015} = 22 000 VND_{2015}.

Straw for cattle feeding

The cost for cattle feed may take more than 50% of total cost. In Vietnam, areas for forage cultivation are much less than in temperate countries in Europe or America. Therefore, straw for cattle feeding is a rational choice even though straw has less nutritional value than forage.

The quantity (dry basis) of cattle feed, from straw or forage, usually equals 3% of the cattle weight (Chau Chau Hoang, personal communication). Thus from birth weight at 13 kg to adult weight at 200-250 kg, a cattle consumes 5 kg of feed per day on average, which is1.8 ton per year. In practice, farmers in Vietnam feeds 7-10 kg a day. The straw may take 60% of the feed; a more amount may affect the weight gain. Thus an easy-to-remember number for cattle is *1 ton of straw/year/head.* This number is used in the balance between straw supply in a specific rice-growing area and straw demand for cattle in that area.

Straw for cattle feed is to be treated with salt, lime, urea, etc. for digestibility and nutrition. In the USA (Table 9), experiments were conducted on the ration of meat cattle and milk cows (Dobie et al., 1973). Note that straw took 70% of the weight of the cattle ration.

Table 9. Composition and cost of rice straw ration for cattle (Dobie et al., 1973)

Composition	% of ration	USD_{1971} /ton ration	USD_{2015} /ton ration	VND_{2015} /ton ration
Rice straw	70.0	--		---
Ground barley	15.0	9.00	40.50	891 000
Cottonseed meal	8.0	7.20	32.40	712 800
Liquid feed supplement	5.0	3.50	15.75	346 500
Urea	1.0	0.80	3.60	79 200
Trace mineral	0.5	0.20	0.90	19 800
Dicalcium phosphate	0.25	0.21	0.95	20 800
Limestone flour	0.25	0.06	0.27	5 900
(Per ton of ration) Total:	100%	20.97	94.37	2 076 000
Per ton of straw:		*29.96*	*134.81*	2 965 800

Note: Conversion rate: 1 USD_{1971} = 4,50 USD_{2015}, and 1 USD_{2015} = 22 000 VND_{2015}.

For chemical treatment, baled straw is more advantageous with a labor productivity of 10-15 times compared to loose straw to obtain a same quantity (interview with Nguyen Loi Duc, An Giang); the unloading from the treated shelter is also more handy with baled straw.

With fast increases of balers in 2014-2016, straw is much more easily transported from surplus areas such as Dong Thap and Long An to nearby provinces with numerous cattle heads such as Ben-Tre, Tra Vinh (Table 7) or Ho Chi Minh city. Moreover, straw began its journey of 1500 km to Nghe An and Thanh Hoa Provinces, where large dairy farms have been established. Assume a minimum of 0.5 kg straw per head per day, a 20 000-cow farm would require 4000 tons of baled and dry straw annually to be shipped northbound.

Mushroom production

Straw mushroom (*Volvariella volvacea*) is a nutritious food that is highly valued in the world market and exported at 1200 USD/ton. The straw rom harvesting one hectare of rice is enough for 200 m² of mushroom bed, which then produces 180- 300 kg of mushroom (250 kg on average) after one month. Estimating as a rule-of-thumb on prices (1 kg mushroom = 3 kg milled rice = 1/3 kg pork meat), the farmer can get a net profit of one million VND (≈45 USD) from that 200 m² of mushroom bed. This is about 15- 20% compared to the profit from selling paddy, and at a shorter period (Phan Hieu Hien, 2013). Furthermore, this does not yet include the benefits from after-mushroom straw residues as organic fertilizer.

Vietnam in 2009 produced 64 000 ton of rice mushroom, 80% of which came from Mekong Delta. This quantity is almost equal to that of Oyster mushroom (*Pleurotus ostreatus*) and is about half of Ear mushroom (*Auricularis*).

Of 50 000 tons mushroom in the Mekong Delta, about 10 000 t comes from Dong Thap Province with the majority from Lai Vung District. Farmers in Lai Vung as well as in some other places of Long An and Can Tho provinces are skillful with mushroom growing; 1000 m² (0,1 ha) of mushroom bed can yield 1 ton of mushroom is common for a household, which is hard to imagine 20 years ago. The yield is 23 tons of mushroom per year on a 1-ha bed.

Not only growing mushroom, some Lai Vung farmers also cultivate inoculum spawn, or process into salted and dried mushroom. Other provinces with annual production of 4000-8000 t/year include Soc Trang, An Giang, Can Tho, Vinh Long; but their yield (in terms of kg of mushroom per 100 kg of straw) is only about half of the yield in Lai Vung.

Mushroom cultivation in the Mekong Delta has faced three *constraints*:

Constraint due to the use of combine-harvesters: In 2010-2013, mushroom production decreased significantly. For example, An Giang in 2012 produced only 1000 ton (t) mushroom, or one-eighth compared to 35 000 tons in 2009. The major cause was the use of combine-harvester that scattered straw over the field (not piling straw from rice threshers as before). Labor for gathering straw was lacking or available at high cost, thus straw cost increased from 200 VND/kg in 2009 to 1600 VND/kg in 2013, or eight-fold.

Luckily, the above constraint has been surpassed by the increase of balers since 2014. Mushroom production has recovered in An Giang and other provinces at least to the 2009's level.

Constraint due to technical problems. The technique for growing mushroom is not stabilized, spawns are often contaminated, which decreases the yield down to 1/3 compared to the above average 250 kg of mushroom per hectare of rice.

The potential for mushroom should be recognized. Although farmers in Lai Vung achieved 10-12 kg mushroom per 100 kg dry straw, the remaining majority only got 5-7 kg. Production at an industrial scale can reach 10-12 kg mushroom /100 kg straw. On a side note, yield is the foremost criteria to determine the economics of mushroom cultivation.

Constraint due to the market. The mushroom market is not stable. About 80% of mushroom quantity is consumed locally, and 20% is exported as salted, canned, or dried products, with an export price of about 2000 USD/t. In the local market, mushroom is considered a *fresh* vegetable. The consumption fluctuates with top sales only in 2 days (first and fifteenth day of each lunar month). On a side note, Ho Chi Minh City consumes about 10 tons of mushroom a day, or 4000 t/year.

Mushroom cultivation in Vietnam is not yet at an industrial scale to meet the export markets, which require high volume, stable quality, and a competitive price. It is mainly a *manual* production, in which labor cost takes 40- 50% of total costs (Phan Hieu Hien et al., 2013). Although socially, it creates employment; but in the long run, the production cost could not be decreased with increasing labor rate. The decrease of mushroom production in An-Giang in 2011-2013 is a timely warning. Thus the future path for mushroom must go for mechanization to be able to compete in the global market. It is not merely by adding one or two machines; but it should be in a value chain from cultivation to processing and marketing.

Exported mushroom in dried or salted forms are not appreciated as they do not keep the original flavor. Fresh mushroom is normally kept for one and a half day and it is impossible to keep it fresh for eight days, which is the minimum timespan for a piece of mushroom to "travel" from the bed out of the country and then wait for 2-3 days at supermarkets until it reaches consumers.

Together with mushroom production, its global market should be considered. To estimate consumers' trend, we can look at the American market: In 2012, the USA produced 417 000 tons mushroom, which valued at about one billion USD. The share of *fresh mushroom* is 87% in quantity, and 93% in value; the remaining minor portion is processed mushroom with a farm-gate price of only 1.4 USD/kg or one half compared to fresh mushroom at 2.8 USD/kg.

The price of fresh mushroom at the USA supermarkets is about 10 USD/kg, while salted mushroom is only 5 USD/kg (Vietnam is exporting at 3 USD/kg). China is annually exporting 1000 ton fresh mushroom to Texas since mushroom can be considered a "clean" product in order to penetrate the USA market; China has developed technologies to preserve fresh mushroom for 7 days which is enough for transportation and marketing (personal communication with Le Duy Thang, 2013).

In short, the global market's demand to preserve fresh mushroom for at least 8 days is the greatest constraint to boost mushroom production, or increase the use of rice straw indirectly.

Rice straw for the paper industry

Rice straw was used for paper-making long ago. Straw was boiled with NaOH to decompose lignine and eliminate some silica (Rymsza, 2004). A mixture of 70-80% of straw pulp and 20- 30% of recycled paper was generally used. Due to disadvantages such as the complicated process and high cost of straw collection and storage, compared to more advanced processes using other materials, now the paper industry no longer uses straw material.

In Bien Hoa, before 1975, Cogido Paper Industries (largest paper company in Southern Vietnam) did use straw for paper pulp. But nowadays, no paper manufacturers uses straw due to the same reasons above.

Straw for energy, thermal and electrical generation

Technologies for converting *wheat* straw to energy have been applied in Europe, with all mechanized operations from field collection to power generation. With *rice* straw, only China has applied the gasification to distribute heating gases for households in rural areas. Sucesses, if any, are lesser known compared to the rice husk gasification for electrical power, and until today thosse teachnologies are not applied in other countries.

In the USA, there were pilot tests on using rice straw in a large power installation, but just to supplement to the existing fuel wood (Jenkins, 2000). The total straw cost (harvesting, transport, and storage) was 52.83 USD_{1999}, or 71.85 USD_{2015}/ton, or 1600 VND_{2015}/kg (conversion rate 1 USD_{1999} = 1.36 USD_{2015}; 1 USD_{2015} = 22 000 VND_{2015}). A blend of 20% of straw and 80% of wood decreased heating value by 13%, increased N, S, SiO_2 (compared to fuel wood) by 44, 58, 94% respectively. The NO_x generated was 2.9 kg /ton blended fuel, compared to 2.2 kg /ton wood, or 32% increase, which was averse to the environment. The ash handling cost increased from 0.69 USD_{2015}/ton for wood to 1.26 USD_{2015}/ton for the blend.

The power cost increased from 0.08 USD_{2015}/kWh (1800 VND_{2015}) for the fuel wood to 0.10 USD_{2015}/kWh (2100 VND_{2015}) for the blend due to the increase in ash handling and straw transport cost. This transport cost was 0.106 USD_{2015}/kWh or 234 VND/kWh at 32-km distance. If the power plant consumed 50 000 tons a year, the transport cost alone would be 260 000 USD_{2015}. Possibly due to that reason, no further development was seen.

In Vietnam, straw has never been considered as a source for power generation, whether at the admimistrative or research level, except for some laboratory-scale tests. There are two reasons: **1)** With the dispersity of straw supply, the transport cost is high. The cheapest way by boat is estimated at 20 USD/ton, or 440 VND/kg for a distance between 30-50 km; **2)** More returns from alternative uses of straw for cattle feed or mushroom growing. We can recapture by considering three tons of straw (from 01 ha) with a total price of 120-180 USD:

03 tons of straw in three years contributes, together with other inputs, to a cattle weight of 200 kg, valued at 10 USD/kg or a total product value of 2000 USD.

03 tons of straw yields a net income of 200-250 USD through cultivating mushroom in about one month after the rice harvest, and replicates for a second harvest of the year.

03 tons of straw can yield 1000 kWh of electricity, at 8 c/kWh (c = USD cent), or a total gross return of 80 USD, which is less than the cost of straw at the power plant (to yield 1 kWh requires 3 kg straw, costing 22 cents). The feed-in-tariff (FiT) of 13 c/kWh as requested by the Vietnamese wind energy sector in 2013 was only accepted at 8 c/kWh. A FiT of more than 22 c/kWh for electricity from straw seems unlikely.

Note: • For cattle raising, besides the 3 tons of straw, another 3 tons of grass/ hay or equivalent are needed; the investment includes the breed young calf at 12 million VND (600 USD); the other major cost is care labor, usually supplied by spare-time family members.

• For mushroom cultivation, three tons of straw yields 250 kg mushroom. The production costs include: inoculum spawn, 60 kg lime; one of the main factor for mushroom cultivation is labor for arranging the bed, watering, harvesting, etc. and supposed to come from the family members.

- The ratio 3 kg of biomass (rice husk, straw, wood, etc.) to 1 kWh electricity is considered common from various literature sources. A better ratio of 2 kg/kWh can be achieved with more modern and expensive technologies.

A study was conducted by FAO at four countries of Asia in 2008 and summarized by Siemers (2012): Proposed FiTs for China, Thailand, and India were 3.7-5.2, 8.2-8.8, and 3.0-4.7 c/kWh respectively. For Vietnam, the 4th country of the study, no FiT was proposed due to its unlikeliness as stated above. Straw for power is not economical versus other alternatives.

For environmental concerns, both burning straw for power and field burning emit about the same amount of green-house gas CO_2, both also increase the earth temperature which is a burning issue that causes earth damage; and both take away organic matters - a precious asset that the "Sun Father" offers to mankind through the photosynthesis process. On the other hand, all other methods of using straw (incorporation, mushroom, cattle feed) return organic matters to the "Mother Earth" in their final stage.

Only one possible way of converting straw to energy remains which is to produce biogas. Residues after gas production still contain organic matters for the earth. The popular method is to mix straw with cattle manure at the proportion 1:1 so as to obtain the suitable C/N ratio for biogas generation (Kalra, 1986).

Production of liquid fuel from straw

Converting straw into liquid bio-fuel is another research topic in the world, especially in Japan. However, to date all results are just at the laboratory scale, not commercialized.

CONCLUSION

As presented, straw utilization can be divided into: (a) use in the field (burning or incorporation), or (b) use out of the field (baling and collection) by various equipment.

It can also be classified as:

(#1): Destruction of straw organic matters (field burning, combustion for power generation).

(#2): Preservation of organic matters (incorporation, mushroom productionr, cattle feed, biogas production etc.).

For the latter classification, method (#1) should be discouraged and eliminated, method (#2) should be promoted in order to return organic matters to the soil. Whether these promotions are carried out within or outside the field, they need mechanized equipment for straw, in similar ways with existing equipment for mechanizing paddy production and milled rice processing. The straw baler as being applied in Vietnam about 2013- 2014 is the starting step for an array of equipment to harvest and to process straw, so as to elevate the straw value in the "triangle" of *Paddy-Milled Rice-Straw*.

REFERENCES

An Giang-Sweden Project. 2014. *An Giang Pitea Project: Introduction*. http://angiang-sweden.com/index.php/en/#

Blank S. C., K. Jetter, C. M. Wick, J.F. Williams. 1993. *Incorporating rice straw into soil may become disposal option for growers*. California Agriculture J., Vol.47, N°4.

Chang D., S. Chung, D. Park, N. Sung, J. Kim. 2012. *The evaluation of a general purpose bale system performance and its bale quality*. Paper N° 12-1340703, ASABE Annual Int'l Meeting, Texas, 29-7-2012.

Dobie J.B, P. S. Parsons, R.G. Curley. 1973. *Systems for Handling and Utilizing Rice Straw*. Transactions of the ASAE, pp.533-536.

Dobie J.B., G. E. Miller Jr., P. S. Parsons. 1977. *Management of rice straw for utilization*. Transactions of the ASAE, pp.1022-1028

GSO (General Statistical Office of Vietnam). 2015. *Data on Agriculture, Forestry and Fishing*. Statistical Publishing House, Ha Noi.

Han Lujia, T.Guanghui, Liu Xiangyang, Yan Qiaojuan. 2003. *Straw resources and utilization in China*. ASAE Paper Number 034164

Hu, C., S. Shang, J. Liu. 2011. *Harvesting and utilization of crop residues as biomass feedstock in China*. Paper N°1110648, ASABE Annual Int'l Meeting, 7-10-2011, Kentucky.

Jenkins B. M., D. A. Toenjes, J. B. Dobie, J. F. Arthur. 1985. *Performance of large balers for collecting rice straw*. Transactions of the ASAE,1985, pp.360-363

Jenkins B. M., R.R. Bakker, R. B. Williams, M. D. Summers, H. Lee, L.G. Bernheim, W. Huisman, L.L Ya, P. Andrade-Sanchez, M. Yore. 2000. *Feasibility of utilizing rice straw in power generation.* http://agris.fao.org/agris-search/search.do?recordID=NL2012063204

Kalra M. S., J. S. Panwar. 1986. *Anaerobic Digestion of Rice Crop Residues*. Agricultural Wastes 17 (1986) 263-269

Kitani O. (Ed.). 1999. *CIGR Handbook in Agricultural Engineering, Volume V (Energy and Biomass Engineering)*. Am. Soc. Agr. Engineers.

Klenin N.I., E.E. Popov, V.A. Sakun. 1985. *Agricultural machines*. Translated from Russian 1970 edition (Kolov Publishers).

Nguyen Thanh Nghi, Nguyen Duc Canh, Hau Duc Hoa, Nguyen Van Hung,, M.Gummert. 2015. *Technical, economic and environmental evaluation on mechanical rice straw gathering method*. Journal of Environmental Science and Engineering B 4 (2015) 614-619

Phan Hieu Hien. 2009. *Study on bioenergy production on from rice residues in Vietnam*. Final report (revised), August 2009. <available upon request at FAO Rome, Italy>

Phan Hieu Hien, Nguyen The Ha, Nguyen Thi Hanh, Vo Thi Ngoc Loi. 2013. *Study on the business model and business plan for mushroom production* (in Vietnamese). Report to the Post-harvest Projects "ADB RETA N° 15" and "CORIGAP IRRI".

Phan Hieu Hien, Nguyen Thanh Nghi. 2013. *Technology assessment for rice residue utilization*. Final Report to SNV (Netherlands Development Organization) Ha-Noi.

Phan Hieu Hien, Nguyen Duc Canh, Tran Van Tuan, Hau Duc Hoa. 2016. *Monitoring and measuring performance parameters of rice straw balers at the Equipment Show on 1-3- 2016 at Can-Tho City* (in Vietnamese). Report to Vietnamese Research and Extension Institutions.

Richey C.B., P. Jacobson, C.W. Hall (Eds). 1960. *Agricultural engineers' handbook*. Mc-Graw-Hill Inc., New York

Rosmiza MZ, W.P. Davies, M. Mazdi, M.J. Jabil. 2014. *Farmers' knowledge on potential uses of rice straw: An assessment in MADA and Sekinchan, Malaysia*. Malaysian Journal of Society and Space 10(5)30- 43.

Rymsza T.A. 2004. *Agricultural residues in pulp and paper: Discussion paper*. www.visionpaper.com.

Siemers W. 2012. *Technical and economic prospects of rice residues for energy generation in Asia. In*: Damen B. & S. Tvinnereim (Eds). Bangkok Conference selected papers, 1 June 2011. FAO, Bangkok.

Sorensen L. 2013. *Hesston large baler passes test of time*. Midwest Producer < http://www.midwestproducer.com/news/crop/hesston-large-baler-passes-test-of-time/article_55546c66-0a76-11e3-b3d0-0019bb2963f4.html >

Summers Consulting, LLC. 2012. *Environmental sustainability report*. Prepared for California Rice Commission.

Summers M.D, B.M. Jenkins, P.R. Hyde, J.F. Williams, S.C. Scardacci, R.G. Mutters. 2001. *Properties of Rice Straw as Influenced by Variety, Season and Location*. Paper N°01-6078, the 2001 ASAE Annual Int'l Meeting, 30-7-2001, California, USA.

Tran Sy Nam, Nguyen Thi Huynh Nhu, Nguyen Huu Chiem, Nguyen Vo Chau Ngan, L Hoang Viet, K. Ingvorsen. 2014. *Estimate of rice straw quantity and and straw treatments at some Provinces of the Mekong Delta* (in Vietnamese). Science Journal of Can-Tho University 32 (2014): 87-93.

Wang D., D.R. Buckmaster, Y.Jiang. 2011. *Rice Straw Silage in Round Bales*. ASABE Paper N°1110792, Annual International Meeting, Kentucky, 7-10 August 2011.

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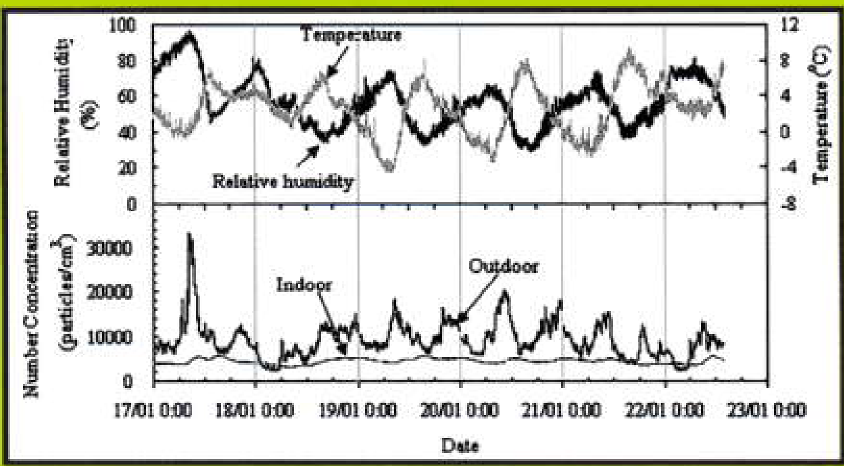

Variations of indoor and outdoor particle number concentrations, and outdoor temperature and humidity

Plywood specimens after 16 weeks of incubation with *C. puteana*

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