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Biomass and carbon distribution on *Imperata cylindrica* grasslands

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Abstract. *Syahrinudin, Denich M, Becker M, Hartati W, Vleg PLG. 2020. Biomass and carbon distribution on* Imperata cylindrica *grasslands. Biodiversitas 21: 74-79.* Invasive plants can alter the diversity and composition of ecological communities leading to ecosystem change both function and biodiversity issues. *Imperata cylindrica* is an invasive grass thrives on wide range of soil fertility and climatic condition forming a vast grassland area of this species. Conversion of such lands into agriculture and plantation is costly and high capital demanding. This work was devoted to investigate CO_2 mitigation potential of the conversion *I. cylindrica* grassland to plantations in Sumatra and East Kalimantan, Indonesia. Stratified sampling technique was applied for the determination of biomass and carbon stock of the system studied. Results show that *I. cylindrica* grassland stored only a relatively small amount of biomass C (5.9-7.6 mg ha^{-1}) implying that conversion into a more C-rich tree-based system would be promising tool to enhance C sequestration. Soil C content at both study sites decreased significantly with depth from the top 15 cm to the 3-m depth and was considerably higher in East Kalimantan than in Sumatra. Provided similar land-use history, the differences in soil C are likely to be related to the level prior to the invasion. Roots of *I. cylindrica* extended to a maximum depth of only 180 cm, but most of these roots being confined to the topsoil, little organic material is deposited in deeper layers. Despite the dense mat of rhizomes, the extent of C stored in the topsoils was modest. As sequestration is of global concern, the conversion of this grassland into systems with higher biomass accumulation and deeper root penetration is required.

Keywords: Biomass, carbon dioxide mitigation, degraded land**,** *Imperata cylindrica*, soil organic carbon

INTRODUCTION

Land degradation is the product of improper land use policy and land management techniques. Low income, inappropriate technology, low input and poor understanding regarding land management have led to huge areas of deforested land in the tropics. In many cases, farmers with land adjacent to forest zones cleared the forests and converted the land into agricultural land to meet their subsistence needs. Due to inappropriate land management systems, much of this area has been abandoned and invaded by *Imperata cylindrica,* the most common weed in the tropics. Today, *I. cylindrica* covers an area of more than 8.5 million ha in Indonesia alone (Soekardi et al. 1993; Garrity et al. 1997).

Imperata cylindrica is a perennial, rhizomatous grass and reproduces from seed and rhizomes; however, flowering is rare and generally occurs only after human disturbance or stress (Sajise 1972). The plant is stemless, growing in loose to compact tufts with slender, flat, linear-lanceolate leaves from the rhizomes (Hubbard et al. 1944). It is a serious pest throughout the tropical and subtropical regions and ranked as the seventh most troublesome weed worldwide (Holm et al. 1977). *I. cylindrica* has been reported to compete for nutrients, light, and water, and cause physical injury to neighboring plants through rhizomes penetrating the roots of these plants (Jagoe 1938; Eussen and Soerjani 1975; Boonitee and Ritdhit 1984). Furthermore, *I. cylindrica* has low nutritional values due to the high C/N ratio, and high lignin and polyphenol contents (Hartemink and O'Sullivan 2001).

The persistent and aggressive rhizomes of *I. cylindrica* are the main mechanism for survival and local spread, which makes the weed difficult to control. *I. cylindrica* is able to invade areas that will not support other vegetation, as it can tolerate a wide range of soil and climatic conditions (Hubbard et al. 1944; Eussen and Wirjahardja 1973; Evans et al. 2007).

Shade, repeated herbicide application, and mechanical control have all been used to control *I. cylindrica* (Macdicken et al. 1997; Terry et al. 1997; Yandoc 2004; Yager et al. 2010). Mechanical control is, however, very labor-intensive and the use of herbicide (Glyphosate) is costly and open to environmental risks. There is the potential of using *Mucuna* in the fallow period to control this grass (Akobundu et al. 2000; Carsky et al. 2001). Nevertheless, because of no direct additional product, acceptance by the farmers in southeast Asia is low.

Imperata cylindrica grass is usually found on soils with low pH, fertility, and organic matter content and soils that are highly leached (Sajise 1980; Wilcut et al. 1988). However, recent studies report that this grass grows fast in a wide range of soils and climatic zones (Garrity et al. 1997; Santoso et al. 1997; Snelder 2001) creating a vast area of unproductive grassland. This is unfavorable from both ecological and economical points of view: low biomass (Otsamo 2002), C accumulation, and biodiversity, enhanced soil degradation and compaction (Ohta 1990); the grass also has very limited use. Moreover, this grassland is susceptible to fire that may extend to the forests in the vicinity of this grassland, resulting in increased coverage. Thus, *I. cylindrica* grasslands emerge as fire-climax vegetation in areas where periodic fires hold back the natural secondary succession of forest (Eussen and Wirjahardja 1973). As a consequence of the unfavorable environmental conditions created by grass competition, allelopathy, fire susceptibility, soil degradation and compaction (Soerianegara 1980; Dela Cruz 1986; Ohta 1990), such grasslands are difficult to reforest or use for agricultural purposes, unless intensive land preparation and management are employed (Otsamo et al. 1997; Otsamo 2002). Land preparation for tree or crop plantations is very labor-intensive and may require 200 man days ha^{-1} (Van Noordwijk et al. 1997) or 800-1000 hours ha^{-1} (Ruthenberg 1976).

However, this grass is susceptible to shade (Eussen 1981; Brook 1989; Otsamo 2002) resulting in reduced carbohydrate storage, rhizome, and tuber-bulb production, shoot dry weight, increased susceptibility to competition and herbicides, and decreased vigor and regeneration (Macdicken et al. 1997). Plantations of fast-growing trees are, therefore, effective in suppressing and elimination of this grass (Turvey 1996; Otsamo et al. 1997). Fast-growing tree plantations may ameliorate the strongly fluctuating microclimate conditions and reverse soil degradation by enhancing soil microbiological activities through increased litter production and nitrogen fixation (Dela Cruz 1986; Ohta 1990; Fisher 1995), thus facilitating the reinvasion of native species (Lugo 1997; Parrotta et al. 1997; Otsamo 2000).

The potential use of agroforestry for the reclamation of *I. cylindrica* grassland has also been reported (de Foresta and Michon 1997; Santoso et al. 1997). While the distribution of *I. cylindrica* grassland, its effect on soil properties and its reclamation potential have been intensively studied, data on the above-and belowground biomass and C distribution of this grassland system are still scarce. Such data are important for determining the baseline of C storage of the system, which can be used in greenhouse-gas mitigation projects such as planting trees in marginal lands. The focus of this study is, therefore, to quantify the biomass and C stock of the system, both above-and belowground, as well as soil-C distribution.

MATERIALS AND METHODS

The study was conducted on the two Indonesian islands of Sumatra and Kalimantan. The sites were selected based on the abundance of the *I. cylindrica* grasslands and the plan for the establishment of plantations in these regions. Observation and sampling for the determination of biomass and C storage of *I. cylindrica* grassland were conducted at both Riau (east of Sumatra) and East Kalimantan sites (Figure 1). Three 3 m x 3 m plots were established on each site. Each plot consisted of three 1 m x 1 m sub-plots. All above-ground biomass of *I. cylindrica* inside the sub-plots was harvested and weighed. Sub-samples were dried to a constant weight at 60°C and dry weight was determined. Thereafter, the samples were ground to pass a 0.2 mm sieve and stored for further chemical analyses.

Root biomass was sampled and collected at 16 drilling points in each plot to a depth of 3 m (using an 8-cm-diameter root auger in 15-cm increments) distributed on a systematical sampling basis (Figure 2). In some cases a less-weathered parent material layer was found at 3 m depth, presenting a physical barrier and preventing sampling for deeper soil layers. Roots were separated from the soil core by water saturation and flushing: soil cores were watered in small flasks overnight for soil suspension. In the case of heavy clayey soils (common for soil layers deeper than 50 cm), calgon (sodium polyphosphate) was added to the suspension to enhance the dispersion capacity of the soils. Hereafter, the suspension was rinsed under a medium pressure water tap and the roots were collected with 2-mm and 65-µm sieves. The samples were processed following the same procedure as for aboveground biomass samples.

Figure 1. Study sites for *Imperata cylindrica* grassland biomass and carbon inventory in Sumatra and Kalimantan, Indonesia

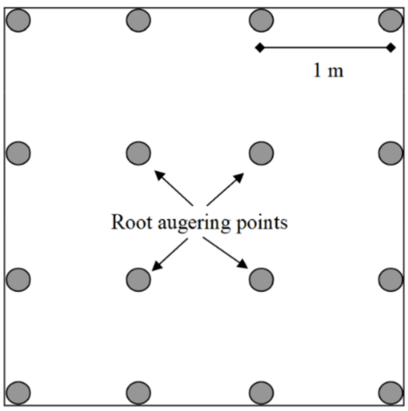

Figure 2. Layout of root sampling of *Imperata cylindrica* grassland at the study sites in Sumatra and Kalimantan, Indonesia

Soil samples for chemical analysis were drawn in line with the procedure of root biomass sampling. A small portion of the soil mass sample was drawn from each soil core of the root sampling. Samples were then mixed to six depth classes, 0-15, 15-30, 30-50, 50-100, 100-200 and 200-300 cm, air-dried and ground to pass a 2-mm sieve.

A soil profile was established nearby one of the three plots on each site for observation of soil morphological characteristics and sampling of soil bulk density. Soil bulk density was sampled at depths of 0-15, 15-50, 50-100, 100-200 and 200-300 cm. Three to six soil core samples were drawn at each depth depending on the range of the soil depth and its presumed variation (3, 4, 5, 6 and 6 core samples for the depths 0-15, 15-50, 50-100, 100-200 and 200-300 cm, respectively).

Carbon and nitrogen (N) content of the samples was determined on the basis of dry combustion with a CNS (C, N, Sulfur) analyzer. Total C of the system was calculated based on C content and mass of each compartment of the system.

Data collected in this research were tested and adjusted to normal distribution (Vasicek 1976) prior to analysis of variance (Fisher 1919) and mean different tests (Fisher 1935) with the help of SPSS software.

RESULTS AND DISCUSSION

Above-and belowground biomass of *I. cylindrica* grasslands varied within and among sites (Table 1). However, the difference was not significant at $\alpha = 0.05$. The aboveground biomass ranged from 6.0 to 10.1 mg ha^{-1}, which is close to the 11.4 mg ha^{-1} in *I. cylindrica* grasslands in South Kalimantan (Otsamo 2002). These values are also in the range that reported for biomass growth rate of 8-20 mg ha-1 (Eussen and Wirjahardja 1973). Although not significant, both above-and belowground biomass of the systems in East Kalimantan site were higher than in Sumatra. This difference may be the result of genetics, environment or seasonal variations of the systems. Nevertheless, since the data were consistent with the organic C of the soils, the results reflect the difference in soil resources. Belowground biomass was higher than aboveground biomass by a factor of 1.5 for the systems in East Kalimantan and by a factor of 1.3 for those in Sumatra.

Table 1. Above-and belowground biomass of *I. cylindrica* grassland at the study sites in Sumatra and East Kalimantan, Indonesia

Site	Biomass (mg ha^{-1})			Below-/above ground ratio
	Above-ground	Below-ground	Total	
East Kalimantan	8.8±1.2	13.1±1.2	21.9±2.4	1.5±0.1
Sumatra	7.4±2.3	9.5±1.9	16.9±4.2	1.3±0.1
	ns	ns	ns	ns

Note: Down to 3 m soil depth; ns not significantly different at $\alpha = 0.05$; three replications

Root biomass of *I. cylindrica* grasslands was distributed to a maximum depth of 180 cm. However, most of the roots were confined to the topsoil layer (Table 2), i.e., 79.5% of the root biomass was found in the top 15 cm and 90% in the upper 41 cm. This implies that the conventional and mechanical elimination of this grass will never succeed, because of the difficulty of removing the deep rhizomes. Measures could be combined with a sound and environmentally friendly chemical application before shade-based (Macdicken et al. 1997) and soil fertility improvement measures (Santoso et al. 1997) could effectively control this grass. The magnitude of root biomass of 12.4 mg ha^{-1} was in the range of that of cool-season grass and switchgrass of riparian buffers of 10.9-16.8 mg ha^{-1} (Tufekcioglu et al. 1999, 2003). Although the biomass of *I. cylindrica* grassland systems is comparable to that the above systems, the distribution in *I. cylindrica* grassland were more concentrated in the upper soil layers: 88.4% of the roots were found in the top 35 cm, while this was 83.0 and 81.0% for the cool-season grass and switch grass systems, respectively (Tufekcioglu et al. 2003; 1999).

Bulk density of soils developed under *I. cylindrica* grasslands ranged from 1.1 to 1.5 depending on site and soil depth (Table 2). The soil bulk density of the East Kalimantan site was slightly lower than that of the Sumatra site. This difference may relate to past land-use history, parent material and the development of respective soils. Bulk density of the soils in East Kalimantan increased with depth, which can be attributed to the decreasing biological activities. At the Sumatra site, bulk density peaked at the depth of 50-100 cm (maximum illuviation horizon) and declined to a depth of 300 cm. The difference in bulk density of soils at Sumatra and East Kalimantan sites could be explained by the difference in root biomass production leading to higher C-organic content of soils at East Kalimantan. Bulk density depends on several factors such as compaction, consolidation and amount of SOC present in the soil but it is highly correlated to the organic carbon content (Morisada et al. 2004; Leifeld et al. 2005). There is strong negative relationship between soil bulk density and soil organic matter (Curtis and Post 1964; Sakin et al. 2011). However, at both sites, bulk density of the topsoils characterized by the dense root biomass (Soepardi 1980; Soerjatna and McIntosh 1980) was significantly lower ($\alpha = 0.05$) than that of deeper soils.

Table 2. Root biomass and bulk density of soils in *I. cylindrica* grasslands at the study sites in Sumatra and East Kalimantan, Indonesia, by depth

Depth (cm)	Root biomass (mg ha^{-1})		Bulk density	
	East Kalimantan	Sumatra	East Kalimantan	Sumatra
0-15	9.9a	7.3a	1.08a	1.11a
15-50	1.5b	1.1b	1.29b	1.36b
50-100	0.9c	0.5c	1.34b	1.50b
100-200	0.2d	0.2d	1.35b	1.43b
200-300	0.0e	0.0e	1.39b	1.37b

Note: Values followed with the same letters are not significantly different at $\alpha = 0.05$.

Even though the bulk density of soils developed under *I. cylindrica* grassland was higher than that of primary forests of 1.0 (top soil) and 1.3 (sub-soil) (Ruhiyat 1989), the bulk density of topsoil of plantations of 1.1 to 1.2 and subsoil of 1.3 to 1.4 (Bremen et al. 1990; Ruhiyat 1989) is comparable to that of under *I. cylindrica* grassland. However, compared to the values reported by Bremen et al. (1990) and Ruhiyat (1989), the increase in soil bulk density from the top-to subsoils of *I. cylindrica* was much more distinct.

Carbon and N content of the aboveground biomass of *I. cylindrica* (40.7% ± 0.7% and 0.62% ± 0.06%, respectively) (Table 2) was higher than that of belowground biomass (30.7% ± 2.2% and 0.56% ± 0.05%, respectively) but only the C content was significant (p of < 0.001 and 0.13, respectively). These values are based on six replications for the aboveground biomass and three replications for the belowground biomass. The C content of *I. cylindrica* leaves of 42.6% reported by Hartemink and O'Sullivan (2001) was quite comparable to that of the aboveground biomass of the present study. This concentration did not much different compared to that of *Piper aduncum* and *Gliricidia sepium* (40.4 and 43.8%, respectively) reported by Hartemink and O'Sullivan (2001).

In line with capacity of *I. cylindrica* to retain most available N in the system to its belowground biomass (Daneshgar and Jose 2009), average C: N ratio of the belowground biomass (55) was lower than that of aboveground biomass (66). However, the values were considerably lower than the 110 reported by Hartemink and O'Sullivan (2001). Compared to that of *Piper aduncum* and *Gliricidia sepium* of 26 and 18, respectively (Hartemink and O'Sullivan 2001), the C: N ratios of *I. cylindrica* were much higher. The rate of decomposition of *I. cylindrica* leaves was much slower than that of *Piper aduncum* and *Gliricidia sepium*, which could not be explained by the C: N ratio alone; the process is also influenced by the lignin plus polyphenol over N ratio (Hartemink and O'Sullivan 2001). It is interesting that the high C: N ratio of *I. cylindrica* does not lead to thick accumulation of organic debris, whether this is attributed to fire frequency or decomposition rate still open to question.

On average, the biomass C of the *I. cylindrica* grassland systems in the East Kalimantan and Sumatra sites was 3.6 and 3.0 mg ha^{-1} (aboveground), 4.0 and 2.9 mg ha^{-1} (belowground) and 7.6 and 5.9 mg ha^{-1} (total), respectively (Table 4). This magnitude is in the range of the biomass C of cool-season grass and switchgrass of riparian buffers reported by Tufekcioglu et al. (2003). Compared to aboveground biomass C of *I. cylindrica* grassland of 1.7-1.9 mg ha^{-1} reported by Ginting (2000) and Lachica-Lustica (1997), the results are somewhat higher, but lower than the 8.5 mg ha^{-1} reported by Lasco et al. (1999). Although belowground biomass was significantly higher than aboveground biomass (p = 0.027), due to the lower C content of the belowground biomass (30.7% and 40.7% for the below-and aboveground biomass, respectively), the belowground and aboveground biomass C did not differ much. The ratio of below-to aboveground biomass C was 1.0 and 1.1 in Sumatra and East Kalimantan, respectively. A similar ratio was reported by Tufekcioglu et al. (2003) for the cool-season and switch grasslands of riparian buffers in Iowa.

Soil organic C and nitrogen are the main limiting factors in grassland productivity and are affected by biomass removal (periodic burning), low input of organic matter and loss of organic matter by surface erosion (Snelder 2001). Soil C content of soils at both sites decreased persistently with depth (Table 5). Values were 1.27 and 1.08% in the top 15-cm depth dropping to 0.15 and 0.10% at the 200-300-cm depth for East Kalimantan and Sumatra, respectively. There was a sharp decrease in the first 15-cm depth to the second 15 cm, after which the C content declined gradually to a depth of 300 cm.

I. cylindrica grassland systems have a dense mat of rhizomes near the surface, which is a positive factor with respect to erosion control and a source of organic material (Soepardi 1980; Soerjatna and McIntosh 1980). It plays a positive role on sloping lands in reducing soil movement and as a vegetative filter for run-off carrying sediments. The relatively high C content of the top 15-cm soil could be due to the abundance of root mass. However, compared to the C content of the topsoil of plantation systems of 1.6 to 2.3% (Bremen et al. 1990; Syahrinudin 1997; Mackensen 1998), the C content of the soils under *I. cylindrica* grasslands is even lower. This is in agreement with the previous finding that the C content of the soils in regularly burnt *I. cylindrica* grasslands tends to decline (Ohta 1990; Van Noordwijk et al. 1997). Furthermore, even though without fire a reasonable soil organic matter level might be maintained, litter quality and subsequent N mineralization are low (Van Noordwijk et al. 1997; Hartemink and O'Sullivan 2001).

Table 3. Carbon and nitrogen content and C: N ratio of below-and aboveground biomass of *I. cylindrica* of studied area

Compartment	C	N	C: N ratio	n
	%			
Aboveground	40,66	0,62	66	6
Belowground	30,71	0,56	55	3
	*	ns	ns	

Note: ns = not significantly different at α = 0.05; * significantly different at α = 0.05

Table 4. Above-and belowground biomass C of *I. cylindrica* grassland at the study sites in Sumatra and East Kalimantan, Indonesia

Site	Biomass C (mg ha^{-1})		
	Above-ground	Below-ground	Total
East Kalimantan	3.6±0.5	4.0±0.4	7.6±0.9
Sumatra	3.0±0.9	2.9±0.6	5.9±1.5
	ns	*	ns

Note: ns = not significantly different at α = 0.05; * significantly different at α = 0.05; three replications

Table 5. Carbon and nitrogen content, C: N ratio and carbon storage of soils in *I. cylindrica* grasslands at the study sites in Sumatra and East Kalimantan, Indonesia

Soil depth (cm)	Sites							
	East Kalimantan				Sumatra			
	C	N	C: N ratio	C storage	C	N	C: N ratio	C storage
	%			mg ha^{-1}	%			mg ha^{-1}
0-15	1.27^{d}	0.13^{b}	10^{b}	20.6	1.08^{c}	0.09^{b}	11^{a}	18.1
15-30	0.88^{c}	0.10^{b}	9^{ab}	17.1	0.70^{b}	0.06^{ab}	14^{a}	14.3
30-50	0.75^{bc}	0.09^{ab}	8^{ab}	19.3	0.57^{b}	0.06^{ab}	13^{a}	15.5
50-100	0.53^{b}	0.08^{ab}	8^{ab}	35.7	0.44^{b}	0.04^{ab}	12^{a}	32.7
100-200	0.27^{ab}	0.06^{ab}	5^{ab}	36.6	0.18^{ab}	0.02^{a}	10^{a}	25.7
200-300	0.15^{a}	0.04^{a}	4^{a}	21.4	0.10^{a}	0.02^{a}	10^{a}	14.0
0-300	-			150.6	-			120.3

Note: Values followed by the same letters are not significantly different at $\alpha = 0.05$

With the exception of the 0-15-cm layer, the C content of the soils at the East Kalimantan site was significantly higher than that of at the Sumatra site ($p < 0.001$). This difference could partly be explained by the difference in biomass production of the system in both sites (Table 1). The rest, since there was no evidence of differences in fire events at these sites, the difference suggests that there was already a difference in the level of soil C content prior to the invasion of *I. cylindrica*.

Distribution of the C storage of soils developed under *I. cylindrica* grassland is presented in Table 5. The results show that the top 50-cm soil depth contributed less than 40% of the total soil C storage to a depth of 3 m, and the contribution of the top 100-cm soil was 61.5-67.0%. This suggests that contribution of the C storage in the deep soils is significant and, due to its high variability, must be assessed. The C storage to a depth of 3 m in this study is quite comparable to that in oxisols of secondary and primary Brazilian forests and traditional crops (130.0-145.0 mg ha^{-1}), but higher than that of oil palm and passion fruit plantations (108.0 and 125.0 mg ha^{-1}, respectively) (Sommer et al. 2000). Little information exists on the C storage in deep soils in the study region; however, the 47.9-56.9 mg ha^{-1} in the top 50-cm soil is still in the range of values for forest plantations (42.1-67.5 mg ha^{-1}) (Mackensen 1998; Syahrinudin 1997; Bremen et al. 1990; Ruhiyat 1989). Nevertheless, compared to secondary and primary forests (57.7-69.9 mg ha^{-1}) (Ruhiyat 1989), the soil C storage of *I. cylindrica* grassland systems is lower.

Of the total 126.2-158.2 mg ha^{-1} C, only 2.3-2.4% were stored in aboveground biomass. Compared to forest ecosystems, contribution of aboveground biomass C to the total C storage of grassland systems is generally much lower (Sharrrow and Ismail 2004).

In conclusion, *I. cylindrica* grassland stored only a relatively small amount of biomass C (5.9-7.6 mg ha^{-1}) implying that conversion into a more C-rich tree-based system would be promising tool to enhance C sequestration. Moreover, the roots of *I. cylindrica* extended to a maximum depth of only 180 cm. With most of these roots being confined to the topsoil, little organic material is deposited in deeper layers. Despite the dense mat of rhizomes, the extent of C stored in the top soils was modest. As sequestration is of global concern, the conversion of this grassland into systems with higher biomass accumulation and deeper root penetration is required. Soil C content at both study sites decreased significantly with depth from the top 15 cm to the 3-m depth and was considerably higher in East Kalimantan than in Sumatra. With similar land-use history, the differences in soil C are likely to be related to the level prior to the invasion.

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