Performance Assessment of Manual Rice Harvesting Methods under Farmer's Field Conditions

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Abstract: A better understanding of field performances for traditional harvesting methods and tools is essential in facilitating future improvement on their design and overall efficiency. Performance of different manual harvesting tools and methods was evaluated under farmer field conditions for IR841 and Nerica L20 rice varieties in Benin. Results from evaluation showed that an average of 84 to 161 man-hours was required to thresh a hectare of rice field using either the threshing by impact "*bambam*" or bag beating method. Less time was however required to thresh IR841 than Nerica L20 varieties, irrespective of manual threshing method used. Similarly, 59 to 91 man-hours was required to harvest a hectare of field using either a cutlass or sickle. However, to harvest Nerica L20 required less time than IR841 variety, irrespective of cutting tool used. Harvesting efficiency ranged from 78.9% to 85.3% with the sickle producing better harvesting efficiency than the cutlass irrespective of rice variety. Energy expenditure ranged from 471 W to 491 W for combine harvesting, 685 W to 1161 W for manual cutting with cutlass, 746 W to 860 W for manual cutting with sickle, 676 W to 873 W during threshing by impact "*bambam*" and 408 W to 409 W during traditional winnowing of threshed paddy. Whereas a mini combine harvester is better at significantly reducing drudgery compared to manual rice harvesting methods, the use of sickle is much preferred to cutlass in the case of manual rice harvesting. However, harvesting IR841 rice variety was generally less laborious than Nerica L20 variety. It is however recommended that further work on performance evaluation of different harvesting systems is carried out under experimental field conditions.

Keywords: harvesting, threshing, Nerica, drudgery, field capacity, cutlass, sickle

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1 Introduction

Rice (*Oryza Sativa* L.) is one of the world's most important food crops. It is estimated that more than half the world's population subsists wholly or partially on rice (Malekmohammadi et al., 2011). Rice cultivation is also the principal activity and source of income for millions of households around the globe, especially countries of Asia and Africa (WARDA, 2005; USDA, 2009). In sub-Saharan Africa (SSA), rice is the most rapidly growing food commodity and is now SSA's second largest source of food energy (Saed et al., 2011; Seck et al., 2013).

IRRI (2015) defined rice harvesting as the process of manually (using sickles or knives) or mechanically (with the use of threshers or combine harvesters) collecting mature rice crop from the field. It must however be stated

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that mechanical harvesting of rice generally saves time, effort and total cost requirements than traditional manual methods (El-Sharabasy, 2007; Takeshima et al., 2013; Paulsen et al., 2015). Although harvesting and threshing operations are known as crucial and influential processes on quantity, quality and production cost of rice (Alizadeh and Bagheri, 2009; Alizadeh and Allameh, 2013), the most common among the developing countries are still the traditional manual methods. Rickman et al. (2013) reported that more than 70% of the rice in Africa is harvested by hand using a sickle, knife or machete. In sub-Saharan Africa for instance, two traditional harvesting methods are dominant; panicle and sickle harvesting. Panicle harvesting provides less harvesting losses when compared to sickle harvesting even though sickle harvesting is much quicker and has the potential of saving time and labour cost (Lantin, 1999; Appiah et al., 2011).

Agriculture in Africa is increasingly becoming unattractive to the youth (Awiah, 2015; Naamwintome and Bagson, 2013) and the rice production sector is not exempted. The high level of drudgery involved, coupled with the unavailability of appropriate technology/equipment, especially during harvesting operations, is a major cause of this situation. According to Djokoto and Blackie (2014), this has led to labour shortages, causing unnecessary increases in labour cost for rice harvesting and threshing in most farming communities.

A report by CARD (2010) identified inadequate appropriate harvesting technology/equipment as a major problem that may constrain rice production in Ghana. This has made it difficult for area expansion as far as production is concerned. Due to poor efficiency of traditional manual harvesting techniques, coupled with acute labour shortages and shorter peak harvesting periods, harvesting and threshing losses have escalated in most developing regions of the world (Komuro, 1995). Having a better understanding of the performances of these traditional harvesting methods and tools is therefore crucial in facilitating future improvement on their design and overall efficiency. Moreover, there is a dearth of information on field performances of the various manual harvesting methods and tools used in most parts of the SSA. Such information will be useful to engineers and other researchers in coming up with sustainable solutions to curb these problems.

The main objective of this study was to evaluate the performance of various manual rice harvesting tools and methods under farmer field conditions. Specific objectives of the study were to:

1. determine the field capacity and field efficiency of manual harvesting with the cutlass and sickle for IR841 and Nerica rice variety.

2. determine the field capacity of the threshing by impact (*bambam)* and bag beating (flail) methods of manual rice threshing for IR841 and Nerica rice variety.

3. measure the drudgery associated with various rice harvesting methods.

4. identify the rice variety, IR841 or Nerica, that better facilitates easier harvesting.

2 Materials and Methods

2.1 Study location and rice variety

The study was conducted on famer's field at Gbaglodji village (07°07′ N 02°21′ E) located in Zagnanado district within the Zou region of Benin. The field was planted to both IR841 and Nerica L20 rice varieties using direct seeding (broadcasting) method.

2.2 Crop conditions

The test condition of crop (variety, duration of crop, grain/straw ratio, grain/straw moisture content, grain size, percentage of damaged grain) were determined using procedures adopted by Amponsah et al. (2017) and Smith et al. (1994). Crop spacing (row and hill), crop height and crop density (plants/m^2) were also determined using appropriate procedures according to Smith et al (1994).

2.3 Moisture content

From each crop field to be harvested, three samples of approximately 0.5 kg each were randomly taken. The samples were placed in sealed plastic containers and taken to the laboratory where the grains and straw were separated by hand. The straw and grains from each sample were kept paired. After weighing with a sensitive electronic scale, the samples were oven dried at 130°C for at least 15 hours and then reweighed. The moisture content (% w.b.) was calculated using Equation 1:

$$Moisture\ content = \frac{weight\ of\ wet\ sample - weight\ of\ dry\ sample}{weight\ of\ wet\ sample} \times 100 \quad (1)$$

2.4 Grain/straw ratio

After determining the weight of the dry samples, the result of the paired samples was used to calculate the mean grain/straw ratio (K) according to Equation 2:

$$K = \frac{weight\ of\ dry\ grain}{weight\ of\ dry\ straw} \quad (2)$$

2.5 Size of grains

From a representative sample of the test material, grains and straw were separated by hand and the size of 50 grains measured. From these measurements, the average diameter and length was determined. Grains were also inspected for damage and the damage calculated as a percentage of the total number of grains sampled.

2.6 Harvesting tools

Two manual harvesting tools, cutlass and sickle were separately used for cutting paddy as reported by Appiah et al. (2011).

2.7 Threshing methods

Threshing by impact (*bambam*) and bag beating (flail) method were each employed for manual threshing after harvesting with the sickle and cutlass. With threshing by impact method, paddy were held by the sheaves and beaten against a steel oil drum (Pegna, 2013). In the case of the bag beating (flail) method, paddy bundles were placed in a sack and beaten severally with a stick to separate the grains from straw.

2.8 Field capacity and field efficiency

Three farmers were each tasked to harvest/thresh the same area of paddy field separately using the harvesting tools or threshing methods one at a time. The field capacity during manual harvesting was determined by recording the time taken to harvest/thresh a given area of field. Harvesting speed was measured as a ratio of distance covered to the required time and expressed in metres per second. Using Equations 3, 4 and 5 as proposed by Hunt (1983), the theoretical field capacity, actual field capacity and field efficiency for each harvesting tool and threshing method were respectively calculated.

$$C_a = \frac{A \times 3600}{10000 \times t} \quad (3)$$

where, C_a = Actual field capacity (hah^{-1})

A = Area harvested (m^2)

t = Total time recorded during harvest (s)

$$C_t = 0.36 \times sw \quad (4)$$

where, C_t = Theoretical field capacity (hah^{-1})

s = Speed of harvest (ms^{-1})

w = Width of cut (m)

$$FE = \frac{C_a}{C_t} \times 100 \quad (5)$$

where, FE = Field efficiency (%)

C_t = Theoretical field capacity (ha/h)

C_a = Actual field capacity (ha/h)

2.9 Harvesting drudgery

A heart rate sensing device (Polar RS 800) was used to obtain the heart rate for each farmer during manual paddy harvesting and for the operator during mechanical harvesting with a rice mini combine harvester, adopting procedures by Amponsah et al. (2014). Using the mean heart rate obtained for a specific field activity to trace for a corresponding energy consumption value on the heart rate-energy conversion chart (Jones, 1988), the Gross energy consumption (Watts) was determined.

2.10 Harvesting quality

Under each harvesting condition (cutting tool and threshing method), three 500 g paddy samples were collected from the total grain yield. Using a sample divider, the 500 g sample was divided into four parts. One quarter being retained for rubbish and damage analysis and result expressed on weight basis. Any green material was allowed to dry for 48 hours under room temperature before it was weighed. Damaged grains and rubbish were then separated by hand in the laboratory (Smith et al., 1994).

2.11 Experimental design and statistical analysis

A split plot layout in randomized complete block design (RCBD) with three replicates was used as follows: rice variety as the main plot treatment and harvesting method/tool as subplot treatment. The results of harvesting trials and field measurements were statistically analysed using GenStat Discovery Edition 3 (VSN International, 2011). The least significant difference (LSD) was used at $p<0.05$ to test difference between treatment means. Analysis of variance (ANOVA) was performed to determine the effects of rice variety and harvesting method/tool on field capacity, harvesting efficiency, drudgery and harvesting quality.

3 Results and discussion

3.1 Crop condition

Grain moisture, straw moisture, grain-straw ratio, hill spacing, row spacing, crop density and crop height for IR841 and Nerica L20 rice varieties at harvest are shown in Table 1.

Table 1 Crop conditions at harvest

Parameter/crop variety	IR841	Nerica L20
Grain moisture content (w.b %)	19.1	20.1
Straw moisture content (w.b %)	21.4	25.7
Grain-straw ratio	1.67	1.27
Grain diameter (mm)	2.73	2.64
Grain damage (%)	2	1.33
Grain length (mm)	9.60	9.90
Hill spacing (cm)	25	23.3
Row spacing (cm)	31	25.7
Crop density (plants m^{-2})	168.3	209.3
Crop height (cm)	100	126.3

Except for hill and row spacing, Nerica L20 rice variety recorded higher values for all other crop parameters studied than IR841 variety. The relatively lower hill and row spacing recorded for Nerica L20 rice variety perhaps could be the reason for its higher crop density and vice-versa in the case of IR841 variety. A study by Sultana et al. (2012) established that rice cultivated at 25 cm × 15 cm spacing gave higher crop density than those planted at 30 cm ×17 cm spacing.

3.2 Harvesting field capacity and efficiency

Figure 5 shows the field capacity recorded during threshing of IR841 and Nerica L20 rice varieties using the threshing by impact "*bambam*" and bag beating methods. Field capacity ranged from 0.0062 hah^{-1} for Nerica L20 variety to 0.013 hah^{-1} for IR841 variety, both using the bag beating method.

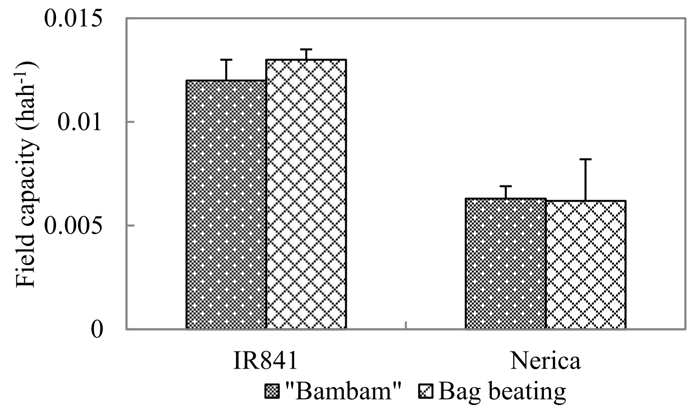

Figure 5 Field capacity of IR841 and Nerica L20 rice varieties versus threshing method

Threshing IR841 rice variety generally recorded significantly ($p<0.05$) greater field capacities for both threshing methods as compared to Nerica L20 variety. This could be due to the fact that Nerica L20 variety naturally has lower grain-straw ratio than IR841 (Table 1). Due to the large volume of straw, more time was required for the threshing; thus the lower field capacity recorded. Moreover, IR841 varieties are easier to thresh than Nerica varieties according to Khan and Salim (2005). However, there was no significant difference ($p<0.05$) in field capacities between threshing methods irrespective of rice variety.

Figure 6 shows the field capacity recorded during harvesting of IR841 and Nerica rice with cutlass and sickle. Harvesting field capacity ranged from 0.011 hah^{-1} for IR841 harvesting with cutlass to 0.017 hah^{-1} for Nerica L20 harvesting with sickle. The range of harvesting field capacities recorded is in agreement with what was reported by Takeshima et al (2013) and Alizadeh and Allameh (2013). Again, harvesting IR841 took significant amount of time than Nerica L20 rice variety, irrespective of cutting tool used. Making an inference from Table 1, it could be due to the fact that Nerica L20 was densely spaced at harvest than IR841 variety. More rice panicles could therefore be cut in one throw of the cutting tool, resulting in the generally higher field capacity recorded for Nerica L20. However, there was no significant difference (p<0.05) in field capacity between cutlass harvesting and sickle harvesting for both rice varieties.

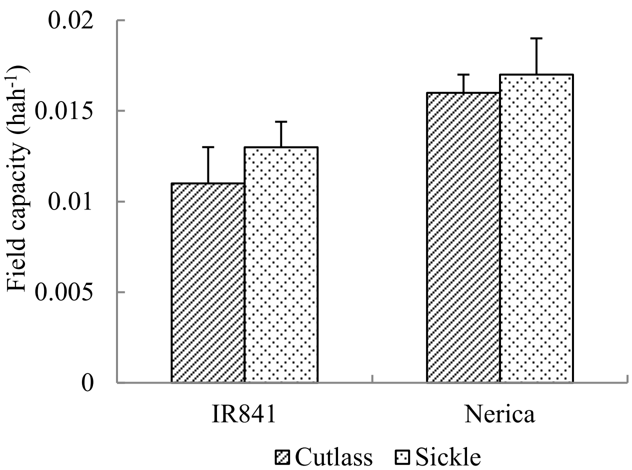

Figure 6 Field capacity of IR841 and Nerica rice varieties as influenced by harvesting tool

The harvesting efficiency for IR841 and Nerica L20 rice varieties using cutlass and sickle is shown in Figure 7. Harvesting efficiency ranged from 78.9% for cutlass harvesting of IR841 variety to 85.3% for sickle harvesting of Nerica L20 rice variety.

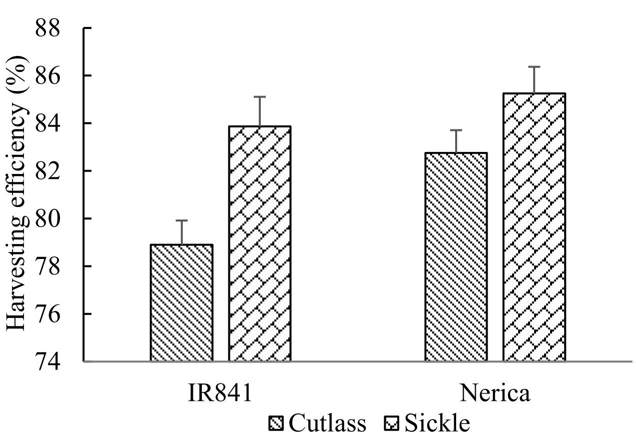

Figure 7 Field efficiency of IR841 and Nerica rice varieties as influenced by harvesting tool

Harvesting Nerica L20 produced greater efficiency than IR841 rice variety, irrespective of cutting tool used. This was because Nerica L20 rice variety was densely spaced than IR841 (Table 1) and thus with one throw of the cutting tool more rice could be harvested in a relatively shorter time, causing the generally higher harvesting efficiency for Nerica L20 variety. However, sickle harvesting offered significantly (p<0.05) greater field efficiency than cutlass harvesting, irrespective of rice variety.

3.3 Harvesting quality

Table 2 shows the percentage grain damage and rubbish content for IR841 and Nerica rice variety after threshing with threshing by impact *"bambam"* and bag beating method.

Table 2 Percentage grain damage and rubbish content for IR841 and Nerica L20 rice variety as influenced by threshing method

Threshing method	Grain damage (%)		Rubbish (%)	
	Rice variety			
	IR841	Nerica	IR841	Nerica
"Bambam"	0.0078	0.0064	0.193	0.023
Bag beating	0	0.0017	0.165	0.03

From Table 2, percentage grain damage ranged from 0% with bag beating method to 0.008% with the threshing drum (bambam) method for IR841 variety. Rubbish content ranged from 0.02% to 0.19% for Nerica under bag beating method and IR841 under threshing drum (bambam) method respectively. It could be seen from Table 2 that IR841 recorded higher percentage grain damage than Nerica L20 variety. Nerica L20, on the other hand, recorded higher percentage grain damage under bag beating method than IR841. It is worth to note that irrespective of threshing method, there was no significant difference (p<0.05) in percentage grain damage between the two rice varieties. However, rubbish content recorded for IR841 was significantly (p<0.05) greater than Nerica L20 rice variety irrespective of the threshing method.

3.4 Harvesting drudgery

Figure 8 shows the energy expenditure during harvesting with the mini rice combine harvester, manual cutting of rice panicles with cutlass and with sickle, threshing and winnowing activities for IR841 and Nerica L20 varieties. Mean energy expenditure ranged from 471 W to 491 W for combine harvesting, 685 W to 1161 W for manual cutting with cutlass, 746 W to 860 W for manual cutting with sickle, 676 W to 873 W during manual threshing with *"bambam"* technique and 408 W to 409 W during traditional winnowing of threshed paddy for both rice varieties.

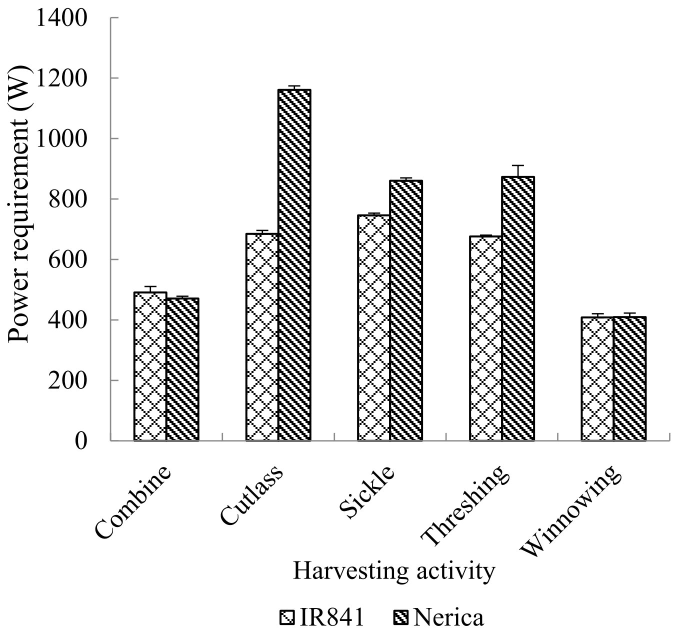

Figure 8 Energy expenditure under various rice harvesting activities for IR841 and Nerica L20 rice varieties

Harvesting rice panicles with cutlass recorded a significantly (p<0.05) greater drudgery than harvesting with the sickle for both rice varieties. Moreover, energy requirement for harvesting (manual cutting with cutlass or sickle and manual threshing with *"bambam"* technique) Nerica L20 was significantly (p<0.05) greater than for harvesting IR841 variety. This could also be attributed to Nerica's low grain-straw ratio and crop density as compared to IR841 variety (Table 1). However, there was no significant difference in energy expenditure between both varieties during combine harvesting and manual winnowing.

It could also be deduced from graph in Figure 8 that energy expenditure for manual cutting (with cutlass or sickle), manual threshing and winnowing combined was significantly greater than harvesting with the mini rice combine. This means that the use of a mini combine harvester is energy-saving than manual rice harvesting methods, which confirms reports in studies by El-Sharabasy (2007) and Veerangouda, et al (2010).

4 Conclusion and recommendations

A range of 59 to 91 man-hours was required to harvest a hectare of field using either a cutlass or sickle. Less time was however needed to harvest Nerica L20 than IR841 variety, irrespective of cutting tool used. Harvesting efficiency ranged between 78.9% to 85.3% for both cutting tools; however, using the sickle offered better harvesting efficiency than the cutlass irrespective of rice variety. An average of 84 to 161 man-hours was required to thresh a hectare of rice field using either the threshing by impact "*bambam*" or bag beating method. Less time was however needed to thresh IR841 than Nerica L20 varieties, irrespective of manual threshing method used.

Energy expenditure ranged from 471 W to 491 W for combine harvesting, 685 W to 1161 W for manual cutting with cutlass, 746 W to 860 W for manual cutting with sickle, 676 W to 873 W during threshing by impact "*bambam*" and 408 W to 409 W during traditional winnowing of threshed paddy. Whereas a mini combine harvester was better at significantly reducing drudgery compared to manual rice harvesting methods, the use of sickle was much preferred to cutlass in the case of manual rice harvesting. However, harvesting IR841 rice variety was generally less laborious than Nerica L20 variety.

Further study on performance evaluation of different harvesting systems under experimental field conditions with respect to reduction of harvesting drudgery is recommended. Rice breeders should intensify work on releasing the likes of the IR841 rice varieties to enhance paddy threshing.

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