Design of a multipurpose agricultural vehicle and attachments for developing countries

David D. Wilson and John H. Lumkes*

(*Purdue University, Department of Agricultural and Biological Engineering 225 South University Street, West Lafayette, IN 47907-2093*)

Abstract: A multipurpose agricultural vehicle, known as the Practical Utility Platform (PUP), was developed by Purdue University in partnership with the African Centre for Renewable Energy and Sustainable Technology (ACREST), a local Non-Governmental Organization (NGO) in Bangang, Cameroon. The practical and simple vehicle is designed to haul 900 kg loads, be a platform to power auxiliary equipment, and pull ground engaging implements. After several design iterations, a vehicle design was developed that is functional, affordable, easy to manufacture, and adaptable for use in a variety of applications. In addition to the vehicle, a simple maize grinder, two-row planter, 3-point hitch caddy, and water pump were designed and tested with the PUP.

The PUP is constructed using locally available parts and materials and can be manufactured on site, lowering the costs, improving sustainability, and increasing local employment. The frame is made entirely of commonly available angle iron. The drive line uses a recycled transmission, drive shaft, and rear axle from RWD vehicles, which are plentiful in Cameroon. The single front wheel uses a front strut from a car while the rear suspension is comprised of coil springs and shocks. The implements and attachments use only basic parts and materials that can be obtained in Cameroon, like angle iron, sheet metal, and wood.

As a vehicle for transportation, the PUP has successfully completed testing both in the U.S. and Cameroon. In April 2012, one prototype was driven over 100 km through mud trails while carrying a 400 kg load and two people. In July 2013, another diesel power PUP prototype was driven a total distance of 100 km during endurance and fuel mileage testing with loads of 70 kg, 500 kg, and 900 kg. The respective fuel economies at these loads were 26, 23, and 18 km/L (62, 53, and 41 miles/gal).Ground engagement capabilities were tested with a 3-point hitch caddy and standard cultivator, a disc plow, and a two-row planter. Several power-take-off (PTO) attachments were also tested, including a water pump and a maize grinder. Fabricating and testing multiple PUP prototypes and implements has demonstrated the resilience of this locally sustainable vehicle and platform.

Keywords: utility vehicles, sub-Saharan Africa, local manufacturing, agricultural vehicles, Cameroon

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1 Introduction

Many places in the developing world, particularly in Sub-Saharan Africa (SSA), lack agricultural machinery and affordable means of transportation, particularly in rural areas. This poses a major constraint to economic growth. In Cameroon, 92% of all roadways are unpaved(The CIA World Factbook n.d.).These roads are often poorly maintained, but are critical for the food system. With only 19 motor vehicles per 1,000 people, vehicle options are limited(World Bank n.d.).Available transportation options are either unreliable, have a small load capacity, or are expensive to purchase and maintain. Imported trucks and cars are expensive and often cannot carry the loads required, especially in poor road conditions. Many affordable motorbikes have been imported and are excellent for carrying a few people or goods quickly to and from the markets, but their capacity is very limited. Because of limited affordable options, people are forced to carry loads manually: a job that often falls to women and children. This lack of mobility has

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***Corresponding author: John H. Lumkes,** Purdue University, Department of Agricultural and Biological Engineering 225 South University Street, West Lafayette, IN 47907-2093. Email: lumkes@purdue.edu.

been a major factor in the suppression of economic development. “Because of poor transport, many rural people remain primarily subsistence farmers, with little impact on the regional economy” (Starkey, 2007).

SSA lags behind other developing regions in the use of tractors, a representative indicator of agricultural mechanization. The absence of appropriate agricultural mechanization limits productivity, the income of individual farmers, and economic growth. Unlike other regions of the world, Africa's agricultural productivity has remained constant. Maize and cereal yields have stayed at about 1000 kg per hectare, approximately one third that of Asia and Latin America (FAO and UNIDO 2008). One reason for this stagnation in productivity is the lack of mechanized solutions for activities related to food production. As of the year 2000, SSA only had 221,000 tractors (Mrema, Baker and Kahan, 2008).In 2007, SSA[2] had 1.1 tractors per 1000ha, significantly below the 11.9average of other developing countries(FAO, 2010).“Farm power in African agriculture relies predominantly on human muscle power, hand tools and draught animal power” (Jenane and Samarakoon, 2012).Even recently, tractor and animal power have declined, “making agriculture yet more reliant on manual methods in a continent where constraints such as severe health problems and demographic shifts make manual labor a scarce and weak resource (FAO and UNIDO, 2008).”Many people in the rural areas of Africasuffer from malaria, which causes fevers, nausea, fatigue, and muscle pain. Food security for farmers in SSA often depends on their ability to work through these health challenges(Thurow, 2012).

Agricultural mechanization is an important part of increasing agricultural productivity. For example, although a part of SSA, Nigeria invested in agricultural mechanization, seeing a 35.5% increase in the use of tractors between 1998 and 2007. During this time, Nigeria's GDP related to agriculture grew by 12.25%. Adelekan attributes this in part to the increased application of machines to agricultural uses (Adelekan, 2012).Without appropriate transportation and agricultural mechanizing technologies, sub-Saharan Africa will likely continue to struggle to develop and increase agricultural productivity.

2 The pup

The Practical Utility Platform (PUP) (Figure 1)is designed to be an affordable utility vehicle for rural transportation and a mobile platform for powering attachments and agricultural implements. Vehicles that perform multiple functions, as opposed to one specific function, can be more valuable to farmers. “In addition to relieving seasonal labour constraints, tractors and animal traction can also be used for other tasks on and off the farm (transportation, driving pumps and grain-milling equipment; maintenance of farm and rural infrastructure)” (Mrema, Baker and Kahan, 2008). Since 2008, Purdue has partnered with the African Centre for Renewable Energy and Sustainable Technology (ACREST) in Cameroon to develop the PUP, which can be manufactured in the ACREST shop, using only basic tools including a welder, grinder, and drill. For the past five years, a team of students from Purdue has traveled to Cameroon to work with ACREST staff to build a PUP prototype.

Figure 1 The 2014 PUP prototype (left) and the 2012 PUP prototype (right)

The use of local materials and manufacturing is important for making the PUP affordable, both to purchase and to maintain. Imported items are difficult to replace and quickly become expensive with import taxes. Therefore, in order to make the PUP affordable and sustainable, only locally available parts and materials are

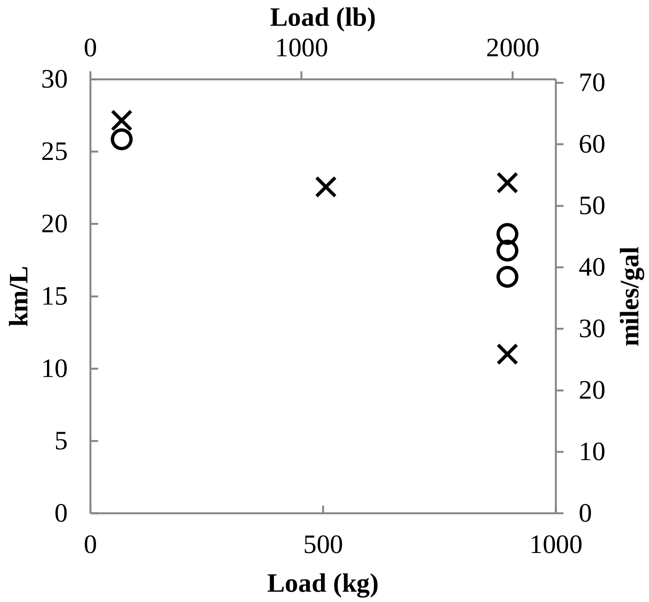
[2] Excluding South Africa

used, which altogether can be obtained for less than 2000 USD. The frame is made out of a single size of angle iron (30x30x3 mm) while recycled car parts are used for the driveline and suspension, along with a few other locally obtainable parts. Many engines in the 6 to 9 kW range can be used to power the vehicle. Details of the PUP design and manufacturing information can be found in, *Manufacturing Agricultural Utility Vehicles in Sub-Saharan Africa*(Wilson and Lumkes, 2015).While primarily a vehicle for transportation, the PUP has been designed to provide power for other agricultural applications. Several agricultural devices were designed to run off a power take-off (PTO) from the engine or to be pulled by the PUP.

Successful testing has been conducted on several prototypes, both in the US and in Cameroon. In a single day, one PUP traversed over 100 km of hilly and muddy trails while carrying a 400 kg load and two people. That PUP has continued to be driven, loaded and unloaded, at different times over the past two years. The last three PUPs built in Cameroon have performed well. They are regularly used by ACREST staff to travel to and from the market and carry loads for other projects. Farmers near ACREST have found value in renting the PUP during harvest to transport their crops, and emissions are reduced compared to using other available mechanized options. On one occasion, the team observed the PUP haul more than 1000 kg to a market 3.5 km away. Both a PUP at Purdue and a PUP at ACREST have successfully run on biodiesel. At ACREST, biodiesel was produced using a process developed by a team from the University of Kentucky (Seay, Zama and Butler, 2012). There are many biofuel options in SSA, including palm oil and Jatropha oil (UN, 2007; Practical Action Consulting, 2009).

One prototype, with a Yanmar L100V, 6.2 kW, single-cylinder, diesel engine and an empty weight of 528 kg, was driven under loads of 70 kg, 500 kg, and 900 kg for a total of 100 km. Fuel economy at the three loadings was 26, 23, and 18 km/L respectively (62, 53, and 41 miles/gal). For each measurement, the vehicle was driven in laps on nearly level gravel roadway for 12 km, on average. Four of the measurements made used non-WAAS enabled smartphones to track the distance covered. These measurements showed more variability and were less accurate. The other four used a WAAS enabled GPS data logger.

Figure 2 shows the data collected with both devices.



Added Weight	GPS Device	Fuel Economy
Kg		km/L
68.0	Phone GPS	27.1
68.0	WAAS GPS	25.8
506.7	Phone GPS	22.5
896.8	Phone GPS	11.0
896.8	Phone GPS	22.8
896.8	WAAS GPS	16.3
896.8	WAAS GPS	19.3
896.8	WAAS GPS	18.1

Figure 2 Fuel economies of the PUP at various loads

One difficulty with the current PUP design that has arisen is with the belt-clutch between the engine and the jackshaft wearing out and breaking. Ongoing research and testing is pointing towards several potential causes. The clutching mechanism is an outside belt idler pulley that can be engaged or disengaged, tensioning or de-tensioning the belt. When the idler is disengaged, the belt jumps around significantly, sometimes catching on the rotating pulley on the engine, or hitting protruding bolts. This can quickly damage the belt. Also, because it is an outside idler, the belt is forced to cycle between being bent inwards and outwards. This fatigue loading puts added stress on the inner material, potentially causing the inside part of the belt to disintegrate. That might mean that the reduced surface area left as a frictional surface between the belt and the pulley is being overstressed, causing the belt to break completely. Finally, loads being carried through the belt might be too high for one belt, requiring a dual or triple belt drive system.

3 Attachments

3.1 Water pump

The PUP acts as a mobile power source. Water pumping is needed in many places both for irrigation and household uses. The PUP can easily power a pump, such as the centrifugal impeller pump pictured in Figure 3. The pump is bolted to a plate that is attached to the frame by a simple pin joint on the edge of the plate. The weight of the pump is supported by the PTO belt on the engine, allowing gravity to tension the belt. The pump can be used to fill containers with water in the bed or can be connected to an irrigation system and is rated for up to 500 L/min.

Figure 3Water pump on the PUP (left) and maize grinder (right)

3.2 Maize grinder

Equipment for post-harvest processing, such as threshing and grinding, can be attached in a similar manner, providing the opportunity for an entrepreneur to travel to rural areas and process farmers' crops. The maize grinder in Figure 3 was designed, built, and tested by a capstone, undergraduate student team. The grinder uses only basic materials including angle iron, plate steel, sheet metal, a shaft, pulley, and bearings.

A small hopper (Figure 4) guides the corn towards the center of the plates, where there is a gap large enough for the kernels to fit in-between the plates. The grinding action is performed by two grooved steel plates(Figure 4).The tapered grooves are deeper near the center and smaller near the outside edge. These grooves were cut using a simple hand grinder, a tool available in Africa. One grooved plate is bolted to the grinder frame and the other is attached to a shaft, which is driven by a gravity-tensioned, v-belt/pulley reduction from the engine.

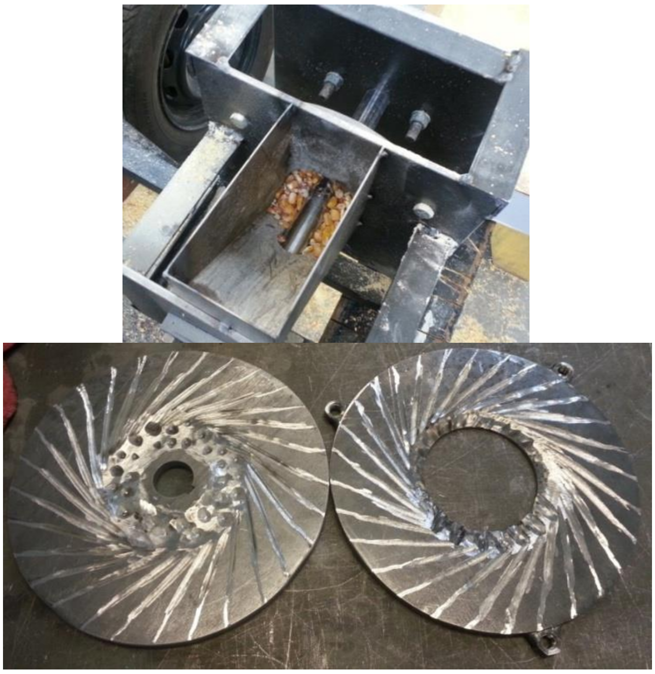


Figure 4 Maize grinder from above showing the hopper with corn feeding into the grinder (left) and the grinding plates (right)

With a 36 cm (14 in.) pulley, the grinder ran at a 4.6 speed reduction from the engine. The engine operates at approximately 1800 r/min(high idle).At 13.3% moisture, 0.68 kg of maize was ground in 4 min for a grinding rate of 10.2 kg/h. The particle size distribution of the ground maize was compared to that of store bought ugali flour. The seiving was done in accordance with ASAE Standard S319.3 (ASABE, 2003). Figure 5 shows the particle size distribution for the store bought flour, the ground maize from one pass through the grinder, and the ground maize after a second pass through the grinder.

3.3 Other potential attachments

With a generator attached in the same way as the water pump and maize grinder, the PUP can act as a mobile electrical power source, which could be particularly useful for welding in remote areas, running power tools, appliances and charging cell phones and other batteries.

The PUP not only offers a platform for power generation but also for mechanizing other agricultural processes like grain threshing. Instead of farmers having to thresh grain manually which can reduce the quality of the grain and is time consuming, a threshing attachment could be designed to power off of the PUP. An attachment like this has the potential to significantly reduce threshing time and increase the quality and quantity of the threshed grain in comparison to conventional methods.

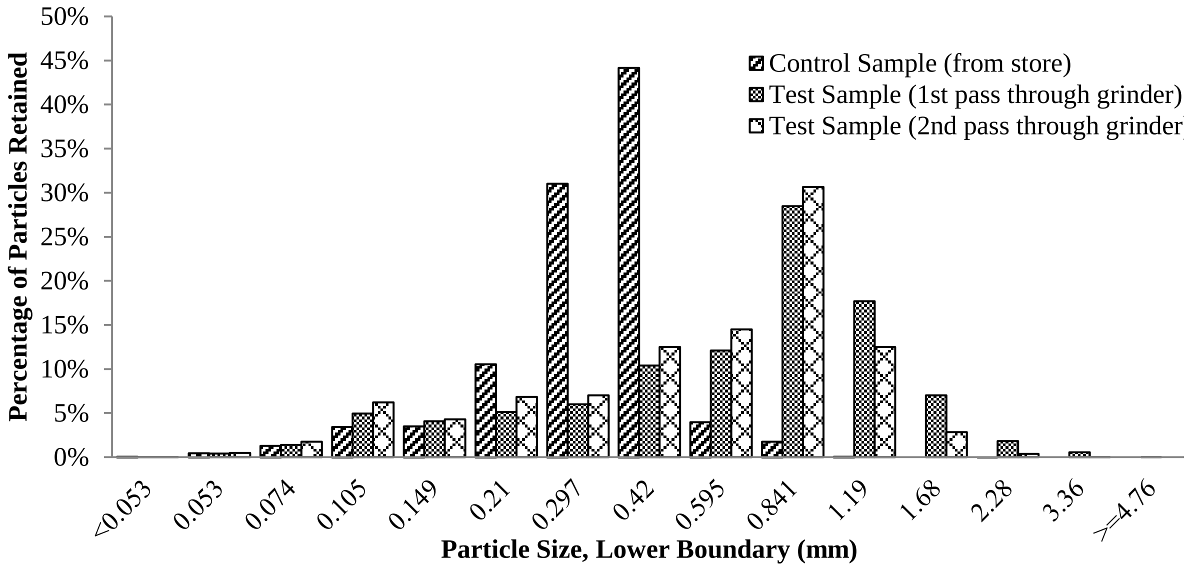


Figure 5 Maize particle distribution

4 Agricultural implements

4.1 Tillage and 3-point hitch caddy

Not only does the PUP provide transportation, it can also power and pull machinery on the farm. The PUP was tested pulling a six-tine field cultivator through sandy loose turf. At the highest reduction and with sufficient weight in the bed, the PUP pulled the cultivator without trouble. To adapt the PUP to be able to pull three-point hitch implements, a two-wheel caddy was made. Like the PUP, the caddy uses locally available parts and materials. The caddy frame was made out of the same size angle iron as the PUP. A scissor jack from a small car was used as the height control of the implement being pulled.Figure 6 shows the PUP pulling the cultivator with the 3-point hitch caddy through some turf and the results of using a cultivator and a small disk plow.

Figure 6The PUP pulling the three-point caddy with cultivator (left) and the results of disk and cultivator (right)

The caddy and implement testing was performed in a heavy sod residue area to imitate a no-till farm. Side-by-side tests were conducted to compare the effectiveness of each implement. The cultivator was set to a depth of 2.5 in. and did an excellent job of burying sod and mixing soil. The disk cut through residue well, but did not incorporate the residue into the soil like the cultivator. Although this method was successful, more work on mechanisms to support conservation agriculture needs to be done.

4.2 Planter

In like manner, the PUP can be used to pull a small planter. A simple two row planter (Figure 7), designed by a student capstone team to use only locally available resources, was also tested.

Figure 7 Two-row planter

As with the other devices, 30x30x3 mm angle iron was used for the frame and tongue of the planter. The planting mechanism for each row of the two-row planter is as follows. While being pulled by the PUP, a steel blade opens a furrow. Behind the blade is a hose coming down from the hopper through which the seeds are dropped into the ground. After that, two blades close the furrow and a press wheel rolls over to pack the earth down. A chain and sprocket assembly from a bicycle drives the metering shaft by the rotation of one of the press wheels. The different sprocket size combinations allows for the metering speed to be easily adjusted. The shaft turns a set of handmade gears, which then turn the wooden seed plate in the hopper. The planting mechanism can be lifted relative to the two supporting tires for transportation between fields. Initial testing of the planter showed some issues with the seed metering system and the furrow closing mechanism. The addition of a simple rake resolved the furrow-closing problem. Further work to solve the metering system has not yet been completed.

5 Conclusion

The PUP addresses many continuing problems seen in Cameroon and similar developing regions. The quality of life for villagers can be improved by enabling them to transport crops and sell them, obtain clean water, and get medical supplies. The current prototypes in Cameroon have directly benefited the villagers in the surrounding area. The addition of a PTO option to power attachments and the ability to prepare the soil with ground engaging implements adds additional value to the platform and allows a single PUP to have multiple income generating and labor saving opportunities.Testing of the PUP has demonstrated its resilience as a utility vehicle and testing of agricultural attachments and implements has demonstrated their added-value potential for farmers. Future goals include resolving the PUP's clutching problems and developing and testing additional attachments, particularly food processing machines.

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