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Design, Development And Testing Of Water Harvesting In Rows Planter (Wahip) For Marginal Rainfed Areas

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Abstracts

Seeding sorghum in the bottom of the ridge has been recommended in areas of low rainfall Eastern Sudan to mitigate water stress. One major constraint that rendered its adoption was the lack of a suitable machine. Providing a planter to achieve such operation can improve sorghum productivity. The objectives of this research were to design, develop and evaluate a planter that can make ridges while seeding sorghum in the bottom. Water harvesting in-row planter (WaHIP) was design and developed for this purpose. It is composed of four-unit-tractor mounted planter combined with a ridger toolbar. The external fluted wheel seed metering type was used and equipped with devices to regulate seed rate. The performance of WaHIP was checked against a row crop planter (RCP) and a wide level disk (WLD) in three sites during two consecutive seasons (2010/2011 and 2011/2012). Some machine parameters, soil moisture content and crop performance and yield were measured. Also socioeconomic and partial budget analyses were carried out. Results showed that WaHIP constructed ridges, seeded sorghum in the furrow simultaneously covered about 2 hectares in one hour at working speed of 8 km/hr. The use of WaHIP resulted in the highest soil moisture, tallest plants and highest sorghum yield in the two seasons. Based on statistical and economic analyses WaHIP is technically feasible, economically profitable and socially acceptable. Therefore it is recommended as an indispensable machine for sorghum production in marginal rainfed areas.

Introduction

The planting operation is one of the most important cultural practices associated with crop production; because increases in yield depend on crop establishment and favorable growing conditions. Methods of row-crop planting can be divided into three categories; namely; in flat surface, in bed and in furrow (Ali, 1996). Kepner, *et al*. (1978) mentioned that furrow planting is commonly practiced under semiarid conditions. This system places the seeds down into the moist soil and protects seedlings from hard conditions.

Ridger shapes the soil into ridge and furrow. It is widely used in irrigated schemes of the Sudan to facilitate irrigation process. In marginal rainfed areas around the irrigated schemes, farmers were fully aware of the benefits of seeding sorghum in the bottom of the ridges. They use ridger to construct ridges while two labors sit on the ridger toolbar trying to broadcast sorghum seeds. The method was known as "*Saireen*". Although this method represents farmers' innovation in dealing with technology gaps, it often results in bad seed distribution with only small portions of the seeds buried and jeopardizes the safety of the labors sitting on the rear of a moving tractor.

Many researchers were involved in the development or modification of seeding machines elsewhere to achieve specific objectives. El-Awad (2003) successfully developed a planter to seed field crops on the top of the ridges in irrigated schemes of Sudan. Abdelhadi, *et al.* (2006) modified a planter to perform ridging and sowing, and used it as a bed planting machine for irrigated wheat in Vertisols of Sudan. Ali, *et al.* (1993) developed a seed drill to form ridge-furrow systems and to seed rainfed crops in the furrow to capture rain water. Ghaffarzadeh, *et al*. (1996) studied the effect of ridger type and its operating parameters on ridge formation; and found that operating depth was the most important factor affecting ridge characteristics.

On the other hand, several studies showed the advantages of ridge-furrow system planting on soil moisture conservation and yield over flat planting in irrigated and rainfed areas (Zhang, *et al*. 2007; Li, *et al*. 2007).

Rainfed agriculture in Gedarif area is extending from South to North, covering about 3.4 millions hectares. Thirty percent of this area is located in the Northern part; which annually receives about 400 mm or less (MFC, 2012). Sorghum is the main crop produced in this part; it is usually sown by the wide level disk (WLD) which broadcasts seeds while shallow-plowing soil surface. This seeding method is associated with low soil water storage and hence often leads to loss of rain water by runoff especially under high-intensity short-duration rainfall events. Adoption of appropriate seeding method such as furrow planting can enhance water conservation and sorghum productivity under marginal rainfed conditions.

Seeding sorghum in the bottom of the ridge was recommended by Elamin *et al*. (2010) and approved by the National Crop Husbandry Committee (NCHC) for the purpose of water conservation in marginal rainfed areas. Unfortunately, no seeding implement was available to turn this recommendation into action. Therefore, the need for such planter is justified especially when the know-how, local facilities and participation may join hands to overcome difficulties and put such challenge into realty.

The objectives of this research work were to:

1. Design and develop a planter that can construct ridges and plant sorghum seeds in furrow simultaneously using common available tractor of 70-80 hp.
2. Assess the performance of the planter and
3. Perform a socio-economic evaluation for the planter.

Materials and Methods

Design criteria of the planter

The most considered criteria for the design were as follows;

1. Operated by a 52 - 60 kW (70 - 80 hp) tractor typically used in rainfed areas.
2. Mounted on 3-point hitch, and its weight matches the lifting capacity of the tractor.
3. Realize the functions of a seeding implement.
4. Drop sorghum seeds in the bottom of the ridge.
5. Simple to construct, safe to operate, and relatively inexpensive to purchase.

Planter development

The planter was made in a workshop in Gedarif town during season 2010 – 2011. All of the requirements for the manufacture were locally available. Figure 1 shows the detailed components of the developed planter.

A ridger of 4 bodies (NARDI make) composed of 4 m toolbar with two gauge wheels was used. The spacing between ridger bodies was 80 cm. The frame in which the planter units were tied was of a rectangular shape of 3 m × o.4 m. It was made from metal angle of 5.1 cm wide and 0.05 cm thickness. This frame was attached to the ridger frame by five linkages via two bolts for each link. Four seed boxes, each was of 0.03 m^3 capacity and of multi – ribs shape, were made from metal sheets of 5 mm thickness. A six cm diameter discharge gate was made in each seed box to ease the replacement or change the seeds in the box. Each seed box was located above ridger unit. The external flute wheel seed metering type was used in each seed box. The seed metering devices of all units operate together. A ground metering wheel with circumference of 210 cm was used to operate the seed metering devices. A compressor spring was assembled to the holding frame of the drive wheel and ridger tool bar. The function of this spring is to keep the drive wheel in contact with the soil to maintain continuous rotation when the planter at motion. A 25 teeth drive sprocket was welded on one end of the center rod (first drive shaft) on the metering wheel and the other end was bolted to the wheel rim. A driven sprocket of 44 teeth was allocated aligned above the drive sprocket and the two sprockets were connected by a chain. Another rod was assembled in the center of the first driven sprocket in one end and the other end was connected with a telescopic universal joint. The later was coupled with the second drive shaft. Four sprockets of different size; 17, 19, 21 and 23 teeth; were assembled in the second drive shaft to facilitate seed rate setting. A final drive shaft of 3.5 m length and square cross sectional area of 16 × 16 mm was made to come through all of the seed metering devices. A sprocket of 27 teeth was fixed on the final drive shaft and connected aligned with the 17 teeth sprocket of the second drive shaft via chain. For seed rate adjustment a hand-operated lever was made and jointed to the final drive shaft to permit the lateral movement of the fluted wheel. Seed tubes of rubber type were made to pass between the wings of each ridger units. Seed cover device of chain type was used in each planter unit. Grease points were assembled to the rotating shafts and rods to prevent seizing and improve work quality of the seed metering mechanism. Finally smooth finishing and painting were made to the planter. The net weight of the planter was 620 kg. The developed planter was named WaHIP which depicts "Water Harvesting In-row Planter" and a synonymous in Arabic meaning "Giver".

Assessment of WaHIP

Assessment of WaHIP was carried out using laboratory tests, general evaluation and field tests as well as socioeconomic analysis. Pre-tests were carried out at the workshop to ensure that all planter parts were assembled properly and functioning satisfactory.

Experimental work

Field experiment was conducted for two consecutive seasons, 2010/2011 and 2011/2012. In the first season the experiment was conducted in Gedarif University Research Farm (GURF); while in the second season it was conducted in GURF and Gedarif Research Station Farm (GRSF). WaHIP was checked against the conventional seeding machine, the wide level disk (WLD) and a row crop planter (RCP). The characteristics of the tested seeding implements were depicted in Table1. The treatments were arranged in a RCBD with four replications. Plot size was 30 × 12 m. Locally improved sorghum cultivar (*Arfa Gadamac*) and a released sorghum variety *Butana* were sown at the required plant density for the first and second season, respectively. Sowing date was in the first week of August in the first season and during the third week of July in the second season. All other management practices were done as recommended by the ARC.

Collected data

Data collected include machine forward speed and work rate, soil moisture content for two depths (0-20 and 20-40 cm) in three times frequency at 30 days interval (in both sites of the second season). Daily rainfall data were also recorded (Table 2). Moreover, crop parameters were collected which include plant population, plant height, head weight, 100 seeds weight and yield.

Socioeconomic study was conducted with 24 farmers and 9 engineers through structured questionnaire. Also partial budget analysis was conducted and necessary data were collected from the reports of the Ministry of Agriculture and Forests, Gedarif state and records of Auction market and service companies.

Results and Discussions

Machines performance

The overall performance of the three implements was almost the same, Table 3. However, WaHIP resulted in the highest working depth (15 to 18 cm) during the two seasons and this due to its design nature. WaHIP has an advantage over the two other implements because it performs two operations; structuring ridges and seeding, in a single pass. This may reduce the cost of seedbed preparation and seeding operations. The working speeds of the tested implements were in the range of 8 to 9 km/hr. The WLD obtained higher value of work rate (2.4 – 2.7 ha/hr) due to higher speed, wider working width and well trained operator. The work rate of WaHIP was 2.1 ha/hr.

Soil moisture content

Results of soil moisture content in both sites for the second season and their combined analysis were presented in Table 4. Seeding sorghum in the bottom of the ridge by WaHIP, as expected, resulted in the highest soil moisture content throughout the season and sites as well as indicated in the combine analysis. Elamin, *et al*, (2010) found similar results. This was due to the fact that WaHIP creates furrow-ridge system which eventually leads to typical micro-catchments water harvesting system allowing more time for infiltration while also conserving moisture by reducing direct evaporation due to the effects of ridge shelter.

Crop performance

Practical application showed that WaHIP has successfully constructed ridges and seed sorghum in the bottom of the ridge at the required seed rates. Fig. 2 demonstrates the performance of sorghum crop grown by WaHIP at different stages.

In the first season, no significant differences between the tested implements in number of sorghum plants established and number of head produced, and head and hundred seeds weights. However, WaHIP resulted in significantly taller plants and higher yield compared to row crop planter (Table 5). This may be attributed to the additional soil moisture that was conserved by the bottom of the ridge sowing method.

In the second season, the resulted sorghum crop performance gave the same trend in both sites (Table 6). Plant population and number of heads were similar for all tested machine, indicating that the developed machine was capable of seeding sorghum at the required plant density. WaHIP resulted in significantly taller sorghum plants (94 cm), the highest head weight (80.19 g) and 100 seeds weight (1.71 g) and grain yield (869.7 kg/ha). The results of final crop yield and yield components indicated the superiority of WaHIP over the other tested machines, especially in the year or areas of lower rainfall. Sorghum grain yield for all the tested implements in the first season was higher than the second season this was mainly attributed to higher rainfall in the first season (Table 2).

Economic analysis

Partial budget analysis

The results of partial budget analysis showed that seeding sorghum by WaHIP was the most profitable compared to the other seeding machines. WaHIP resulted in the highest cost of investment, gross return and net return in both seasons (Table 7a). The marginal analysis was conducted based on the WLD and RCP seeding machines, as typical conventional seeding used by farmers. The marginal rate of return of WaHIP was 498.8% and 535.5% for the WLD and RCP, respectively. This indicates that for every one SDG invested in seeding sorghum by WaHIP will return back about 4 to 5 SDG (Table 7b).

Socioeconomic analysis

A random sample consisted of 24 farmers and 9 agriculturists were interviewed about WaHIP. All of the respondents were over 33 years, married and have variable levels of education, indicating their maturity and responsible assessment. Their response results were shown in Table 8. All respondents have great willingness to possess and use WaHIP for seeding their crops, indicating their satisfaction and acceptance. Most of the respondents (88%) mentioned that the seeding performance of WaHIP was good and none of them had any negative comment, moreover, they recommended it for seeding sorghum. About 88% of the respondents reported the excellence of WaHIP compared to WLD in performing seeding operation. Only 18% reported difficulty in operating WaHIP. The majority of the respondents (97%) mentioned the suitability of the machine for seeding rainfed crops, especially in the low rainfall areas (Northern and Central Gedarif). They noted that seeding crops by WaHIP helped in conserving rain water. All of the respondents reported the feasibility and profitability of WaHIP.

Early adoption of WaHIP

The Ministry of Agriculture in Gedarif State had fabricated 4 planters typical to WaHIP as a consequence of its demonstration and good performance. These planters were used in technology transfer promotion by demonstrating them at four sites in different locations. Also farmers showed positive perception towards WaHIP and they began to adopt and fabricate it individually. Moreover, some private workshops in Gedarif started to produce the machine with minor modifications from the original design.

Conclusions

For the two seasons of the study (2010/11 and 2011/12), the following conclusions could be drawn:

1- Water harvesting in row planter (WaHIP) was developed and tested in comparative manner to conventional seeding machines. It is a four-unit-tractor mounted planter jointed to a ridger toolbar, and it fulfilled the intended design and operation criteria.

2- It's successfully seeded sorghum in the bottom of the ridges in marginal rainfed areas with an average field work rate of 2.1 ha/hr.

3- WaHIP obtained the highest grain yield and tallest plants compared with row crop planter and wide level disk.

4- The marginal rate of return indicated the profitability of WaHIP.

5- WaHIP has been accepted by farmers and engineers and they began to adopt it.

6- WaHIP is technically feasible, economically profitable and socially acceptable.

7- WaHIP can be used for seeding sorghum in the bottom of the ridge for the purpose of soil moisture conservation in marginal rainfed areas.

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Table 1. Characteristics of the tested seeding machine treatments

Seeding machines	Working width, m	Hitch system	Seed metering type	Seeding pattern	Seed covering device
WaHIP	3.2	Mounted	Flute roller	Ridge bottom	Chain type
RCP	3.2	Mounted	Horizontal plate	flat-in row	Paddle type
WLD	3.7	Trailed	Flute roller	flat-broadcast	Disks action

WaHIP = water harvesting in rows planter, RCP = row crop planter, WLD = wide level disk.

Table 2. Rainfall data for the experimental sites in two seasons

Site	GURF		GURF		GRSF	
Seasons	2010 – 2011		2011 – 2012			
Months	Rain (mm)	Rainy days	Rain (mm)	Rainy days	Rain (mm)	Rainy days
Jul	191.6	6	92	6	4.3	2
August	174.6	12	176.6	14	196.7	9
Sept	84.9	5	25.7	4	54.5	5
Oct	17.6	3	0	0	0	0
Total	468.7	26	294.3	24	255.5	16

GURF = Gedarif University Research Farm
GRSF = Gedarif Research Station Farm

Table 3. Implements performance data, during cropping seasons 2010-011 and 2011-012

Implements	Speed (Km/hr)	Work rate (ha/hr)	Working depth (cm)
Season (2010/2011)			
WaHIP	8.4	2.2	18
RCP	8.0	1.9	3
WLD	9.0	2.7	6
Season (2011/2012)*			

WaHIP	8.0	2.1	15
RCP	8.1	2.1	3
WLD	8.2	2.4	7

WaHIP = water harvesting in rows planter, RCP = row crop planter, WLD = wide level disk
* Average of two sites

Table 4. Effect of tested implement on soil moisture content percentage (two sites)

Reading date	12/9/2011		11/10/2011		15/11/2011	
			GURF			
Depths, cm	0 -20	20– 40	0-2 20	20- 40	0 -20	20– 40
WaHIP	37.6	30.7	26.9	24.8	18.7	17.2
RCP	36.4	27.5	25.0	22.6	17.3	15.2
WLD	33.9	27.2	22.1	22.5	16.7	15.2
C.V. (%)	5.45	4.6	7.69	4.01	6.59	6.11
SE	0.98	0.65	0.95	0.47	0.58	0.48
			GRSF			
WaHIP	31.9	28.3	24.5	28.8	17.9	16.7
RCP	28.0	23.8	21.3	21.6	16.8	15.4
WLD	27.2	22.8	21.1	22.2	16.5	15.2
C.V. (%)	7.28	7.45	7.71	8.10	5.13	3.46
SE	1.06	0.93	0.86	0.91	0.44	0.27
			Combine analysis			
WaHIP	34.8	29.5	25.7	24.3	18.3	16.9
RCP	32.2	25.6	23.2	22.1	17.2	15.3
WLD	30.5	25.0	21.6	22.3	16.7	15.2
C.V. (%)	6.98	7.46	8.33	6.76	6.35	6.25
SE	1.13	0.99	0.98	0.77	0.55	0.49

WaHIP = water harvesting in rows planter, RCP = row crop planter, WLD = wide level disk
GURF = Gedarif University Research Farm
GRSF = Gedarif Research Station Farm

Table 5. Effect of tested implement on sorghum performance, in the first season

Implements	Plants/m^2	Plant ht (cm)	No of heads/m^2	Head wt. (g)	100 seeds wt. (g)	Yield (kg/ha)
WaHIP	8.4	130.6	8.4	37.37	3.13	3141.70
RCP	9	122.0	9	26.07	2.91	2144.80
WLD	8.4	125.8	8.4	32.34	3.22	2687.74
C.V. (%)	17.18	2.92	17.18	20.66	6.91	18.56
SE	0.66	1.65	0.66	2.95	0.095	220.57

WaHIP = water harvesting in rows planter, RCP = row crop planter, WLD = wide level disk.

Table 6. Effect of tested implements on sorghum yield, for the two sites, in season 2011/2012

Implements	Plants/m^2	Plant ht. (cm)	No of heads/m^2	Head wt. (g)	100 seeds wt. (g)	Yield (kg/ha)
			GURF			
WaHIP	8	95	8	85.9	1.84	969.600
RCP	8	88	7	63.6	1.67	578.350
WLD	7	81	6	61.3	1.61	507.925
C.V. (%)	11.71	5.63	17.87	5.3	6.32	11.78
SE	0.45	2.47	0.62	1.86	0.05	40.38
			GRSF			
WaHIP	7	93	5	74.49	1.58	769.8
RCP	7	88	4	62.20	1.31	497.7
WLD	6	88	4	59.40	1.26	471.3
C.V. (%)	11.47	2.41	15.86	25.48	10.35	6.91
SE	0.36	1.08	0.34	8.33	0.07	20.01
			Combine analysis			
WaHIP	8	93.8	7	80.19	1.71	869.7
RCP	7	87.6	5	62.90	1.49	538.0
WLD	6	84.1	5	60.32	1.44	489.6
C.V. (%)	13.64	10.05	16.63	19.33	10.72	10.95
SE	0.48	4.45	0.48	6.55	0.08	34.62

WaHIP = water harvesting in rows planter, RCP = row crop planter, WLD = wide level disk.
GURF = Gedarif University Research Farm.
GRSF = Gedarif Research Station Farm.

Table 7a. Partial cost of sorghum in rainfed areas using different seeding machines

Treatments	Average cost (SDG/ha)	Gross return (SDG/ha)	Net return (SDG/ha)
RCP	517.3	1121.0	603.7
WLD	531.3	1231.8	700.5
WaHIP	628.9	1718.6	1089.8

WaHIP = water harvesting in rows planter, RCP = row crop planter, WLD = wide level disk

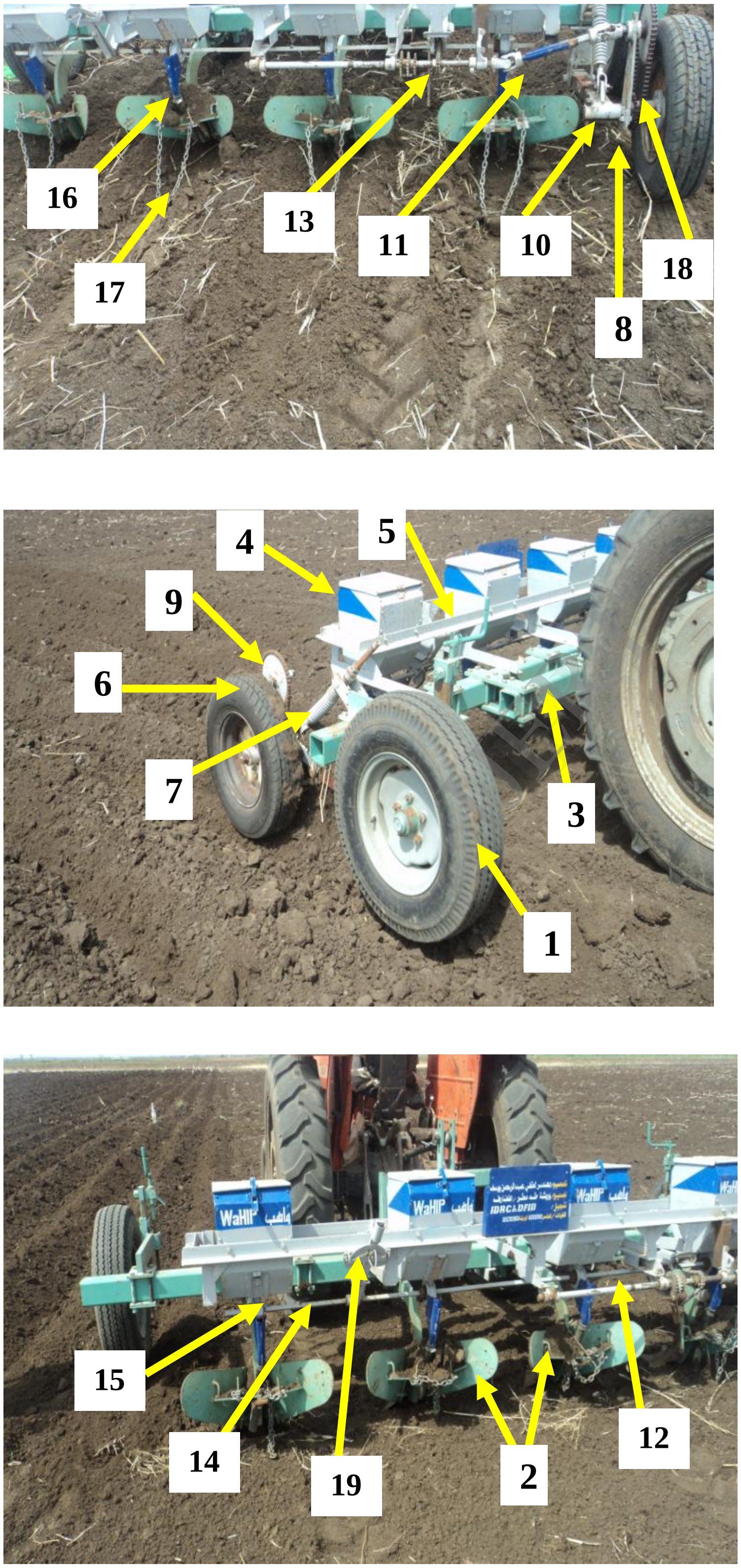
Table 7b. Marginal analysis of sorghum seeding machine for two seasons (2010/2011 and 2011/2012)

Treatments	MC	MR	MRR (%)
RCP			
WLD	111.6	597.6	535.5
WaHIP	97.6	486.8	498.8

WaHIP = water harvesting in rows planter, RCP = row crop planter, WLD = wide level disk
MC = marginal cost, MR = marginal revenue, MRR = marginal rate of return

Table 8. Socioeconomic data analysis and evaluation

Social evaluation		
Education level	Frequency	Percent
Primary	3	9
Intermediate	9	27
Secondary	12	37
Graduate	7	21
Postgraduate	2	6
Primary job		
Farmer	24	73
Agriculturists	9	37
Willingness to posses WaHIP and to seed crops by WaHIP		
Willing	33	100
Not willing	0	0
Technical evaluation		
Suitability of WaHIP for seeding sorghum		
Suitable	33	100
Not suitable	0	0
Operation of WaHIP		
Difficult	6	18
Normal	22	67
Easy	5	15
Validity of WaHIP for rainfed crops		
Valid	32	97
Not valid	1	3
Suitable regions for using WaHIP		
Central	3	9
North	9	27
North + central	21	64
Seeding performance of WaHIP compared to WLD		
Excellent	29	88
Good	4	12
Poor	0	0
Seeding performance of WaHIP compared to WLD		
Good	29	88
Faire	4	12
Poor	0	0
Moisture conservation		
Conserve	33	100
Not conserve	0	0
Economic evaluation		
Economical feasibility of WaHIP		
Feasible	33	100
Not feasible	0	0



1- Ridger gauge wheel
2- Ridger bodies
3- Ridger toolbar
4- Seed box
5- Seed box frame
6- Drive wheel
7- Loading spring
8- First drive sprocket
9- First driven sprocket
10- Center rod
11- Universal joint
12- Second drive shaft
13- Second drive sprockets
14- Final drive shaft
15- Seed metering device
16- Seed tube
17- Seed covering chain
18- Connecting chains
19- Hand lever

Fig.1. Detailed components of WaHIP

(a) Early stage of sorghum sown by WaHIP

(b) Mid stage of sorghum sown by WaHIP

(c) Maturity stage of sorghum sown by WaHIP

Fig.2. Sorghum performance when sown by WaHIP