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# A Comparison of Performances of Conventional Tillage Implements Versus Namibia Specific Conservation Tillage Implements under Ogongo, Namibia Conditions

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**Abstract**

Studies were conducted over a period of three years (2011 to 2013) at the Ogongo Campus of the University of Namibia (UNAM), to compare the differences between two conventional tillage (CV) treatments (i.e. tractor-drawn disc harrow (TDH) and animal-drawn mouldboard plough (AMP) and two Namibia Specific Conservation Tillage (NSCT) treatments (tractor-drawn ripper furrower (TRF) and animal-drawn ripper furrower (ARF). The objective was to test and compare the field performances of two implements each for the NSCT and CV technologies on (i) depth of cut, (ii) width of cut, (iii) draught of the power source (iv) efficiency and (v) effective field capacity under Ogongo conditions. The research design was a randomised complete block design. Results showed that the NSCT technologies (TRF and ARF) performed better in terms of the depths of cut than CV technologies (TDH and AMP) in all the three years but the NSCT technologies also resulted in higher draught forces than the contemporary CV technologies. The specific draught of NSCT technologies were however less across the three seasons showing that they were more energy efficient than CV technologies. Tractor drawn tillage methods resulted in lower specific draught than animal-drawn tillage methods across the three years. None of the tractor-drawn implements in the study met the ASAE Standards of Efficiency (70-90%) with the TDH achieving field efficiencies of 44% (short by 16%) and TRF achieving 62% (short by 8%). Across the three years, the effective field capacities for tractor-drawn tillage methods were: TDH = 0.68 ha $hr^{-1}$, TRF = 0.74 ha $hr^{-1}$.

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For animal-drawn tillage methods, the effective field capacities for AMP = 0.03 ha $hr^{-1}$ and for ARF = 0.15 ha $hr^{-1}$. Overall the field performances of NSCT implements were better than those of CV implements and farmers should be encouraged to choose NSCT methods.

***Keywords:*** Namibia; Namibia specific conservation tillage; ripper furrower; Implement performance; comparison; tractors; animals; draught force; specific draught; efficiency; effective field capacity.

**1. Introduction**

Conservation tillage (CT) is generally defined as any tillage sequence whose objective is to minimize or reduce the loss of soil and water. It is operationally defined as any tillage or tillage and planting combination which leaves 30% or more mulch or crop cover on the surface [1]. Conservation tillage practices simultaneously conserve soil and water resources, reduce farm energy and increase and stabilise crop production [2]. This is crucial for Namibia with a climate that can be described as semi-arid to arid. Traditional soil cultivation systems, with intensive soil tillage, generally leads to soil degradation and loss of crop productivity [3, 4]. Farmers in the Northern communal areas (NCA) of Namibia practice Conventional Tillage (CV) i.e. mouldboard ploughing, disc ploughing and harrowing [5 - 7]. These practices, especially when high-speed disc harrows are used, pulverise the soil thereby destroying the soil structure. They also destroy vital organic matter and create hardpans and plough lines. This leads to soil degradation resulting from erosion, both biological and mechanical. As a result, there occurs a rapid decrease in crop yields [5 - 8]. World-wide, the focus of sustainable farming has shifted to conservation agriculture, and sound tillage systems are an integral part of it. In Namibia, a method that makes use of the animal-drawn and tractor-drawn ripper-furrowers to rip and make furrows in one operation was introduced into the Northern Communal Areas NCA [5, 9]. The method is termed the Namibia Specific Conservation Tillage (NSCT). The technology emphasizes the use of mulch, manure and crop rotations and it is also explained in detail in the Volume 1 of this paper [8] and in [9]. The first paper [8] reported on the differences in the agronomic parameters (root development and yield of pearl millet) among the different treatments of Conventional and Namibia Specific Conservation Tillage Methods in Ogongo, Namibia. This paper will look at the differences in the technical/field parameters among the different treatments of Conventional and Namibia Specific Conservation Tillage Methods in Ogongo, Namibia. The parameters looked at are Draught force, Specific draught, Field Efficiency, Effective Field Capacity, width of cut and depth of cut. Draught and power requirements are important parameters for measuring and evaluating field performance of tillage implements so that implements can be matched to the right sizes of power sources (in this case, animals and tractors) and also the right operations. Various studies conducted to determine the draught and power requirements of tillage implements under various soil conditions gave the factors that affect draught requirements as: soil texture, depth of cut, geometry of implement/tools [10 -15], speed, width of cut, weight, and moisture content of soil [11, 12, 14, 16 - 29]. To assess the differences in draught requirements of different implements accurately, the draught requirement must be related to the volume of soil tilled [24, 30] given as the Specific Draught which is defined as the implement's draught divided by the rectangular area of all the soil that is moved by the implement. The Specific Draught of agricultural tools and implements varies widely under different factors and conditions [19, 27, 31, 32]. Field Efficiency refers to the time a machine actually spends in the field doing exactly what it is supposed to do as compared to the total time the machine spends in the field

[12, 33]. Typical ranges of Field Efficiencies for most of the field machines, can be found in [34, 35] and are given as 70–90%. According to [36], three factors important for determining the Effective Field Capacity are: machine width or size, operating speed, and time spent in operation.

### *1.1 Objectives and Hypotheses*

The objective of the study was to compare the field performances of two implements each for the NSCT and CV technologies on five parameters viz: (i) depth of cut, (ii) width of cut, (iii) specific draught of the power source (iv) field efficiency and (v) effective field capacity under Northern Namibia conditions. The tillage implements are a tractor-drawn disc harrow and an animal-drawn mouldboard plough, representing the CV technology and a tractor-drawn ripper-furrower and an animal-drawn ripper-furrower representing the NSCT technology. In order to achieve the objective, it was hypothesised that the implements used for the NSCT technologies will exhibit significantly different field performance characteristics in terms of depth of cut, width of cut, draught force, specific draught, efficiency and effective field capacity when compared to the corresponding implements used for the CV technologies at the 95% CI.

## 2. Materials and Methods

On-station tests and trials were conducted at the Ogongo Campus of the University of Namibia in the Omusati Region of Namibia. The rainfall is seasonal, falling mostly between the months of November and April. The recoded rainfall therefore decreased from 2011 to 2013. The implements tested were: (i) animal drawn mouldboard plough (AMP); (ii) animal drawn ripper furrower (ARF), (iii) tractor drawn disc harrow (TDH) and (iv) tractor drawn ripper furrower (TRF). The research was set up in a randomized complete block design. Each block had a total of 4 tillage treatments giving a total of 16 plots. The plots measured 10m x 10m, with 5m borders between blocks and 2m between plots to allow proper turning and movement of tractors and animals. The specifications of the power sources (tractors and donkeys) and the CV and NSCT implements used are outlined in [8, 9] and repeated here (Table 1) for clarity. The draught force measurements for the tractor drawn implements followed the method described in literature [39 - 41]. Two tractors, a John Deere 5415 (65kW) and a John Deere 2351 (55kW) were used. A Novatech F 256 Axial Compensated Load cell (10kN) was used in combination with a TR150 portable load meter to measure both tractor and donkey draught force (Figures 1 and 2). The load cell and the portable load meter were attached to the front of the 55 kW tractor. Using a steel chain, the 65kW tractor was then used to pull the 55kW tractor in neutral gear over a 10m distance after which the draught was recorded. The implement was then mounted on the 55kW tractor in the operating position (but with the tractor still in the neutral gear). The 65kW tractor was then used to pull the 55kW tractor mounted with the implement through the load cell attached to the front of it, over a 10 m distance and the draught was recorded. The draughts within the measured distance of 10 m, as well as the time taken to reverse it, were both recorded. The difference between the two readings, i.e. loaded minus unloaded, gave the draught of the implement. The 55kW tractor was later mounted with each of the implements separately and the draught was measured again for each implement. This procedure was repeated for each of the implements evaluated. The different parameters i.e. depth of cut, width of cut, draught, time per run, time for turning were measured following the methods recommended by [42]. Five readings were taken for each of the parameters from a digital display on the TR150 portable load meter attached to the load cell at ten randomly selected places in the four middle rows of each plot.For the implements mounted on the donkeys, the draught force was also measured using the Novatech F 256 Axial Compensated Load cell (10kN) and a TR150 portable load meter attached to the front of the implement between the harnesses swingle tree and implement in draught chain. The speed, depth of cut width of cut were measured using standard methods and the measured parameters were then used in establishing the specific draught, EFC or hr ha[1] and Field Efficiency.

**Table 1:** Specification of the power sources and tillage implements

| Power source | Implement | Tillage system | Implement Specifications | Width of Implement |
|---|---|---|---|---|
| **3 Donkeys** Total mass - 673.2 kg | Standard animal-drawn single furrow plough (AMP) | Conventional tillage | Standard V8 mouldboard plough | 0.2 m |
| **3 Donkeys** Total mass - 673.2 kg | Animal-drawn ripper furrower (ARF) | Namibia Specific Conservation Tillage | Baufis ripper-furrower | 0.1m |
| **Tractors** John Deer 5415 (65kW) and 2351 (55kW) | Tractor-drawn offset disc harrow (TDH) | Conventional tillage | Offset .20 discs | 2.2 m |
| **Tractors** John Deer 5415 (65kW) and 2351 (55kW) | Tractor-drawn ripper furrower (TRF) | Namibia Specific Conservation tillage | Baufis 2-tine | 1.85m |


**Figure 1:** Novatech F 256 Axial Compensated Load cell and a TR150 portable load meter

One of the limitations of this study is the non-availability of some of the instruments earmarked for collecting data. For example, the initial plan was to use depth transducers and a dynamometer with datalogger for the automatic and more accurate recording of the tractor-implement performance measurements. These instruments could not be acquired due to lack of funds. However, the Novatech F 256 Axial Compensated Load cell (10kN) and a TR150 portable load meter used were found to be adequate in collecting data that were sensitive enough to expose the variances among the performance parameters for different treatments. The Proc Mixed analysis [43] was used to highlight differences in the field parameters namely: depth of cut, width of cut, draught force, draught power, specific draught, efficiency, and effective field capacity data among the treatment groups (implement type and technology types) over the three agricultural seasons. The Univariate Procedure [43] was used to obtain univariate statistics (means, standard deviation, CV, range) for the different variables. Alternative models were compared by running the Proc Mixed model [43] with various covariance structures. Covariance structures can be objectively computed using goodness of fit criteria [44] by Proc Mixed model, including the REML log likelihood (RELM Log L), Average (Akaike) Information criteria (AIC) and the Schwarz's Bayesian Information Criteria (BIC). The value of information criteria closest to zero indicates a better model fit to the data [45]. The statistical model used for this analysis is defined in equation 1. The same model below was used across all covariance structures to allow easy comparisons. The model described in equation 1 was also used for all field parameters. The fit statistics for the five covariance structures for draught force were calculated. A smaller model fit statistic value indicates a better fit to the data.

$$Y_{ijt} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijt} \qquad (1)$$

Where:

$Y_{ijt}$ = is the $t^{th}$ measurement (depth of cut; width of cut; draught force; specific draught, efficiency, effective field capacity) on a plot under the $i^{th}$ tillage method in the $j^{th}$ year

$\alpha_i$ = the effect of the $i^{th}$ year (i = 1, 2, 3)

$\beta_j$ = is the effect of the $j^{th}$ tillage method (j = 1, 2, 3, 4)

$(\alpha\beta)_{ij}$= is the interaction effect between $i^{th}$ tillage method and $j^{th}$ year

$\varepsilon_{ijt}$ = is the random error associated with the $t^{th}$ specific draught measurements on a plot under the $i^{th}$ tillage method in the $j^{th}$ year.

## 3. Results

The results for the treatments TRF: tractor-drawn ripper-furrower (NSCT); ARF: animal-drawn ripper-furrower (NSCT); TDH: tractor-drawn disc harrow (CV); AMP: animal-drawn mouldboard plough (CV)) and implement performances concerning depth of cut, width of cut, draught force, specific draught, efficiency, effective field capacity, at land preparation for implements are presented for three agricultural seasons, i.e. 2010 -2011, 2011-2012 and 2012-2013.

### *3.1 Analysis for all parameters*

Table 2 shows the least square means summaries for all the parameters i.e. depth of cut, width of cut, draught force, specific draught, efficiency, effective field capacity for the two CV and the two NSCT technologies in the three years.

### *3.2 Univariate Statistics for Field Performances of CV and NSCT Technologies.*

Table 3 summarizes the univariate statistics for all the variables for the two CV and the two NSCT technologies in the three years. Differences on variables are presented in the subsequent sections.

### *3.3 Summary Fit Criteria Analyses and ANOVA*

The fit statistics for the five covariance structures for the depth of cut are presented in Table 4. A smaller model fit statistic value indicates a better fit to the data. Based on the BIC, the TOEP structure was selected for depth of cut. The other five i.e. width of cut, draught force, specific draught, effective field capacity and efficiency were analysed the same way as shown in Table 4 for the depth of cut. The summary of fit criteria for all the six parameters is presented in Table 5.

**Table 2:** Means of Performance Parameters for different tillage methods and Years

| Effect | Tillage Method | Year | Depth (m) | Width (m) | Draught Force (kN) | Efficiency (%) | Tractor EFC (ha $hr^{-1}$) | Animal EFC (ha $hr^{-1}$) | Specific Draught ($kN.m^{-2}$) |
|---|---|---|---|---|---|---|---|---|---|
| Tillage method | AMP | | 0.095 | 0.211 | 0.706 | 0.622 | | 0.030 | 35.480 |
| Tillage method | ARF | | 0.137 | 0.161 | 0.831 | 0.631 | | 0.148 | 35.856 |
| Tillage method | TDH | | 0.124 | 1.871 | 4.135 | 0.544 | 0.687 | | 21.696 |
| Tillage method | TRF | | 0.292 | 1.764 | 6.344 | 0.615 | 0.742 | | 11.393 |
| Year | | 2011 | 0.151 | 1.115 | 1.199 | 0.621 | 0.823 | 0.094 | 18.628 |
| Year | | 2012 | 0.167 | 0.949 | 3.167 | 0.604 | 0.647 | 0.098 | 27.358 |
| Year | | 2013 | 0.168 | 0.942 | 4.645 | 0.584 | 0.674 | 0.075 | 32.333 |
| Tillage vs year | AMP | 2011 | 0.079 | 0.203 | 0.502 | 0.665 | | 0.032 | 30.219 |
| Tillage vs year | AMP | 2012 | 0.091 | 0.213 | 0.770 | 0.630 | | 0.030 | 40.211 |
| Tillage vs year | AMP | 2013 | 0.114 | 0.218 | 0.848 | 0.570 | | 0.028 | 36.010 |
| Tillage vs year | ARF | 2011 | 0.130 | 0.126 | 0.736 | 0.648 | | 0.156 | 35.852 |
| Tillage vs year | ARF | 2012 | 0.132 | 0.178 | 0.868 | 0.630 | | 0.165 | 37.292 |
| Tillage vs year | ARF | 2013 | 0.149 | 0.179 | 0.888 | 0.615 | | 0.123 | 34.423 |
| Tillage vs year | TDH | 2011 | 0.142 | 2.167 | 1.377 | 0.523 | 0.772 | | 4.323 |
| Tillage vs year | TDH | 2012 | 0.128 | 1.725 | 4.113 | 0.548 | 0.616 | | 19.008 |
| Tillage vs year | TDH | 2013 | 0.101 | 1.723 | 6.915 | 0.563 | 0.673 | | 41.758 |
| Tillage vs year | TRF | 2011 | 0.255 | 1.963 | 2.183 | 0.648 | 0.875 | | 4.116 |
| Tillage vs year | TRF | 2012 | 0.315 | 1.680 | 6.918 | 0.610 | 0.678 | | 12.921 |
| Tillage vs year | TRF | 2013 | 0.307 | 1.650 | 9.930 | 0.588 | 0.674 | | 17.141 |

**Table 3:** Univariate statistics for field performances of CV and NSCT technologies.

| Statistic | Depth (m) | Width (m) | Draught force (kN) | Efficiency (%) | Tractor EFC (ha $hr^{-1}$) | Animal EFC (ha $hr^{-1}$) | Specific draught (kN $m^{-2}$) |
|---|---|---|---|---|---|---|---|
| N | 136 | 144 | 144 | 144 | 72 | 72 | 141 |
| Mean | 0.15 | 1.00 | 3.00 | 60.29 | 0.72 | 0.09 | 25.89 |
| Median | 0.13 | 0.83 | 0.96 | 60.50 | 0.70 | 0.08 | 27.95 |
| Mode | 0.13 | 0.20 | 0.80 | 60.00 | 0.69 | 0.03 | 33.33 |
| Std. Deviation | 0.078 | 0.833 | 3.123 | 0.488 | 0.091 | 0.061 | 15.65 |
| Variance | 0.006 | 0.693 | 9.75438 | 0.0238 | 0.008 | 0.004 | 244.929 |

**Table 4:** Fit criteria for depth of cut

| | Covariance structure | BIC | REML log L |
|---|---|---|---|
| 1 | CS | -536-5 | -544-2 |
| 2 | UN | -540-0 | -563-2 |
| 3 | AR (1) | -536-8 | -544-6 |
| 4 | TOEP | -533-1 | -544-7 |
| 5 | SIMPLE | -538-7 | -542-6 |
| 6 | HF | -542-5 | -558-0 |
| 7 | ANTE (1) | -543-7 | -563-1 |

CS = compound symmetry; UN = Unstructured; AR (1) = First order auto regressive; TOEP = Toeplitz; HF = Huynh-Feldt; ANTE= First order Ante- dependence

**Table 5:** Summary of fit criteria for all variables

| Variable | **Covariance structure** | **BIC** | **REML log L** |
|---|---|---|---|
| Depth of cut | TOEP | -533-1 | -544-7 |
| Width of cut | SIMPLE | -273-0 | -276-9 |
| Draught | ANTE(1) | 182.2 | 162.8 |
| Specific draught | ANTE(1) | 928.4 | 909.1 |
| Efficiency | SIMPLE | -575.8 | -579.7 |
| Effective field capacity | SIMPLE | -228.8 | -232.0 |

CS = compound symmetry; UN = Unstructured; TOEP = Toeplitz; HF = Huynh-Feldt; ANTE= First order Ante- dependence

The ANOVA results for all the parameters i.e. depth of cut, width of cut, draught force, specific draught, efficiency, effective field capacity for the two CV and the two NSCT technologies in the three years are shown in Table 6. The ANOVA results for all the six parameters showed that all factors were highly significant.

**Table 6:** Summary of ANOVA results for six parameters

| Variable | **Pr > F** | | |
|---|---|---|---|
| | **Tillage** | **Year** | **Tillage vs year** |
| Depth of cut | <.0001 | 0.0012 | <.0001 |
| Width of cut | <.0001 | 0.0012 | <.0001 |
| Draught | <0.0001 | 0.0001 | <0.0001 |
| Specific draught | <0.0001 | 0.0001 | <0.0001 |
| Efficiency | <.0001 | 0.0001 | <.0001 |
| Effective field capacity – animals | <0.0001 | 0.0001 | <0.0001 |
| Effective field capacity- tractors | <0.0001 | 0.0001 | <0.0015 |

### *3.6 Specific Draught Analysis*

Several researchers have pointed out that, to assess differences between different implements accurately, the draught requirement must be related to the volume of soil tilled i.e. specific draught [24, 30]. Following the equation and model comparison equation 1, the fit statistics for the five covariance structures were estimated. Based on the BIC, the ANTE depended covariance structure was selected as reported in Table 5. Table 7 shows the ante-dependence estimated covariance and correlation matrices for replicate 37 and plot 1 for the three years of the study; other plots have the same covariance and correlation matrices. The estimated covariance matrix indicates there is considerable variation in specific draft across years. For example, the variance in specific draft in 2011 is about 6 times that for 2012. Table 7 also indicates weak correlations in the specific draft measurements across the years of the study.

**Table 7:** Ante-dependence Covariance and Correlation Matrices for Specific Draught

| Estimated R Matrix for rep 37 (plot 1) | | | |
|---|---|---|---|
| Row/ Year | Col 1 (specific draught) | Col 2 (specific draught) | Col 3 (specific draught) |
| 1 | 144.69 | 0.9733 | 0.4090 |
| 2 | 0.9733 | 24.1260 | 10.1386 |
| 3 | 0.4090 | 10.1386 | 51.2841 |
| Estimated R Correlation Matrix for rep 37 (plot 1) | | | |
| Row | Col 1 | Col 2 | Col 3 |
| 1 | 1.0000 | 0.01647 | 0.004748 |
| 2 | 0.01647 | 1.0000 | 0.2882 |
| 3 | 0.004748 | 0.2882 | 1.0000 |

Based on the ANOVA results shown in Table 6 the specific draughts are significantly different across years.

### *3.7 Effective Field Capacity Analysis*

All the tillage methods were first analysed together for Effective Field Capacity (EFC), and as the distribution was found to be bimodal, they were further analysed separately, i.e. animal group on its own and tractor group also on its own. For tractor-drawn implements, the EFC for TRF decreased from 2011 to 2013, whereas for the EFC for TDH decreased in 2012 and then increased again in 2013.

## 4. Discussions

### *4.1 Depth of cut analysis*

Depth of cut was significantly different ($p<0.001$) across treatments, with the TRF method having the highest average depth over the 3 years, whilst there was not much difference among the remaining three methods. In 2011, comparing the tractor group, TRF went 44.3% deeper than TDH, and in the animal group ARF went 30.8% deeper than AMP. In 2012, within the tractor group, TRF again performed better, by going 59.5% deeper than TDH. In the animal group ARF went 30.9% deeper than AMP. In 2013, the same trend appears in both the animal and tractor groups. The TRF outperformed TDH by 67.2%, and ARF outperformed AMP by 23.5%. Overall, NSCT methods were superior to CV methods in terms of depth of cut, regardless of power source. TRF is the tillage method that can achieve deepest cut of depth.

### *4.2 Width of cut analysis*

Within the tractor group, a wider cut was achieved under the TDH than under the TRF by 9.4% in 2011, by 2.6 % in 2012 and by 4.2% in 2013. In the animal group, a wider cut was achieved under the AMP compared to the ARF by 38.1%, in 2012 by 16.3% and in 2013 by 17.6 %. There were increases in the width of cut over the years for the implements in the animal group (AMP and ARF) whereas TRF and TDH showed decreases in width of cut over those years.

Observations on the formation of furrows by the NSCT implements showed that good furrows were made under TRF, but not under the ARF even though both NSCT implements were expected to make furrows that could potentially harvest water. TRF is the best method for making furrows that can harvest water.

### *4.3 Draught Force Analysis*

For animal-drawn implements, the draught force for AMP (CV) in 2011 was lower by 31.8% than for ARF (NSCT). In 2012, on the other hand, ARF’s draught force was less by 4.4% and in 2013 AMP (CV) used a 4.6% lower draught force than ARF.

Among the tractor -drawn implements, TDH (CV) used lower draught than TRF (NSCT). In 2011, the draught force used for TDH was 36.9%, lower than for TRF, 40.6% in 2012 and 30.4% in 2013. Although the draught force increased for all tillage methods from 2011 to 2013, the increase was much greater for tractor-based tillage methods compared to animal-based tillage. For example, under TRF the increase was 4.5 times, compared to 1.7 times for AMP.

Overall, the NSCT implements required higher draught forces than the CV ones, probably because they had to push larger volumes of soil in order to make furrows. As reflected in Table 3, the depth of cut under TDH was also lower than under TRF; while AMP similarly achieved a lower depth than ARF. This also explains the lower draft forces required for CV methods. TRF and ARF achieved greater depth of cuts than CV methods, thereby explaining the higher draught forces as compared to TDH and AMP.

The increase in operation speed from 6.5 to 6.7 km.h$^{-1}$ from 2011 to 2013 due to change of operator could also have been responsible for increased draught force. This is supported by various researchers who cited increase in speed as contributing to increased draught force [12, 14, 17, 18, 23- 25, 27].

The draught force was higher for ARF, indicating that the animal-drawn plough (CV) was more efficient than ARF (NSCT). The result of Nengomasha [46] for donkey draught force for AMP of 823N was slightly higher than the experimental results in the present study for 2011 and 2012, but lower than those for 2013 ( 502N to 848 N). An explanation for these differences and also supported by various researchers [47, 48]; could be that the draught force that animals exert to draw an implement constantly changes due to numerous interacting variations attributable to the animals, the operator who can greatly influence the performance of tillage methods [49, 50], the soil and the orientation of the implements.

***4.4 Specific Draught Analysis***

The specific draught for AMP increased from 30.2 kN m$^{-2}$ in 2011 to 40.2 kN m$^{-2}$ in 2012 but decreased to 36.0 kN m$^{-2}$ in 2013. The specific draught for ARF also followed the same pattern, as reflected in Table 3. Within the animal group, the specific draught for ARF was less than for AMP in all three years. The specific draught for AMP in 2011 decreased by 5.6% in 2012; the specific draught for ARF decreased by 2.9% and in 2013 it was 1.6% less. This means that ARF was more energy efficient than AMP. Overall, the high specific draught registered in the animal-drawn implements is very likely due to the small volume of soil which was disturbed, i.e. small depth and width of cut.

Within the tractor group, specific draft increased greatly under TDH from 2011 to 2013 while it also increased under TRF, but the increases are not as pronounced as those of TDH. The specific draught of TRF in 2011 was less than that for TDH by 4.8 %; i by 32.0% in 2012 and by 59% in 2013. This means that TRF was more energy efficient than TDH.

Overall, the NSCT methods performed better than the CV methods on specific draught. The NSCT implements required higher draught forces than did CV ones. The NSCT methods, however, operated with less specific draught than the CV methods. TRF and ARF showed lower specific draught than TDH and AMP across the three years, suggesting that NSCT methods were more energy-efficient than CV methods.

Various researchers also showed that depth has a greater effect on draught and that this subsequently affects specific draught [13, 14, 17, 20 – 23, 27 – 29, 39, 51- 53]. They also recommended that ploughing depth should be based on the type of crop and the depth of the root system. Other researchers have also suggested that specific draught is affected by working depth and implement configuration [31] the soil type and condition, ploughing speed [52], plough type, shape, friction characteristics of the soil-engaging surfaces, share sharpness and shape, depth of ploughing, width of furrow slice, type of attachments, and adjustment of the tool and attachments. The tillage energy data thus need to be combined with other agronomic and soils data to select the optimum tillage system for a particular soil and climatic region. The major lessons from this are not to work deeper than necessary and to work at a greater forward speed to increase work rate [39].

Year of measurement was found to have an influence on specific draught (p <0001). The models in the present study provided important insight into the variations of depth, draught and specific draught with year. They revealed that, in dry years, high specific draught could be expected. These models need, however, to be supported by large data sets, and more work would need to be done. It would have been easier to model under ‘soil bin’ conditions, where one is able to control certain variables in the same conditions [54]. Soil bins can also help to minimize capital costs and moderate the manual labour requirements, but might miss out on some of the realities of the field.The present experimental results for draught forces as reflected in Table 9 are higher than those given by Hunt [12] with TRF 39% higher and TDH 13% higher, but they are lower than those given by ASAE [34]. These differences in implement draught suggest that substantial energy savings can readily be obtained by selecting energy-efficient tillage implements. Whilst TDH required less draught force, it gave higher specific draught values compared to TRF, making TDH less efficient. Reduced soil cultivation, in this case with TRF, reduces farm energy requirements and overall farming costs because a smaller area has to be worked on during tillage [55].

**Table 9:** Comparison of performance of experimental tractor drawn implements with ASAE and Hunt

| | Experimental TDH | Experimental TRF | Hunt [12] | ASAE **(**34**)** |
|---|---|---|---|---|
| Speed km $hr.^{-1}$ | 6.5-6.7 | 6.5-6.7 | 6-10 | 6.5-11 |
| Draught kN | 6.9 (2013) | 9.9 (2013) | 5-6 | TRF = 18.03<br>TDH = 10.35 |
| Efficiency % | 52.3 - 56.8 | 58.8 -64.8 | 75-90 | 70- 90 |

***4.5 Efficiency Analysis***

Within the animal group, in 2011, the field efficiency under AMP was better than under the ARF by 2.7%; whilst they were the same in 2012 but the efficiency of ARF was better than that of AMP by 7.3%. As for the tractor-drawn implements, the field efficiency of TRF was better in 2011 than that under the TDH by 19.3%; 10.3% in 2012 and by 4.3% in 2013.

In comparing, the field efficiency values for tractor drawn implements for this study were 19% (TDH) and 7%

(TRF) short of the ASAE Standards of Efficiency [34] standard D497.4), i.e. 70–90% (Table 9). This could be because of the shorter rows used in this study and lack of experience of the operators. According to Von Bargen, cited in [12] differences in ability, motivation, alertness, and training of an operator can have significant effects on operator's performance. Whilst TDH was found to be the least efficient in this study, this implement is used mostly by the tractor service providers in the NCA, despite it being shown to pulverise the soil [5]. This therefore reinforces the point that the TDH, which is a conventional tillage implement, should not be the preferred implement to use for land preparation purposes in the NCA.

Animal-drawn implements could not achieve high efficiencies because of the variation in the performance of animals and alertness of the operators. This is in agreement with [49] and [56] who mentioned that the performance of an implement sometimes depends on the skill of the operator as well as soil conditions. In the present study, AMP's efficiency ranged from 57% to 67% which only managed to reach the minimum efficiencies of 66.7%–83.3% as established by [57].

Comparing the NSCT with the CV implements, TRF and ARF (NSCT) were more efficient than TDH and AMP (CV). Whilst TDH had an improved efficiency over the years, it was nonetheless the least efficient because the tractor had to turn with a larger implement, thereby taking more time to turn than was required with other implements. The plots used in this study were also small, so it is expected that with bigger plots or fields, the efficiency is bound to improve. Efficiency decreased across the three years, from 2011 to 2013. Apart from the smallness of the plots, this could also be attributed to changes in operator. Different operators were used in each of the three years.

### *4.6 Effective Field Capacity Analysis*

The animal-drawn ripper-furrower (NSCT) could do 0.15 ha hr-1 compared to the 0.03 ha hr.1 for AMP (CV). Working for six hours per day, this would amount to 0.89 ha cultivated per day for ARF and 0.18 ha for AMP. The results show that increasing the width of cut also increases the EFC. This is in line with [39] who also showed that increasing the width of the implement increases the work rate, i.e. effective field capacity. Results from this study showed that NSCT was better than CV.

Considering that the ARF causes relatively little soil disturbance and can finish a field faster than AMP, as shown in the present study, it is recommended that Namibian farmers should choose ARF. Compared to AMP, using ARF (NSCT) will effectively reduce the amount of time that the animals would need to spend in the field. Reducing energy requirements is crucial for the semi-arid areas of Namibia, where draught animals are often weak during the time of land preparation [61]. By implication, cultivating using ARF would also lead to yield increases as farmers can plant early. Studies in Zimbabwe [62] have shown that 5.1% of cereal potential grain yield is lost for every week of delay in planting.

For tractor drawn implements, the EFC of TRF decreased from 2011 to 2013, whereas for the EFC for TDH decreased in 2012 and then increased again in 2013. Generally, both tractor-drawn methods showed a decrease of EFC by 2013. In 2011, the EFC of TRF was better than that of TDH by 11.8%, by 9.2% in 2012 and by 0.2 %

in 2013. In all the three years, cultivating with ARF resulted in greater EFC than cultivating with AMP. Similarly, cultivating with TRF resulted in better EFC than TDH in all the three years. In other words, both NSCT methods performed better than their corresponding CV methods regardless of power source.

## 5. Conclusions

In conclusion, there were significant differences in depth, draught force, specific draught, efficiency and effective field capacity among tillage methods. NSCT methods (TRF and ARF) were shown to have be advantageous over CV methods when used in the Ogongo sandy soils, but justification for implementing the system would be dependent upon site-specific field conditions. However, cultivating with ARF alone in the first year may not be adequate and will have to be complemented with TRF. Though the NSCT technologies also resulted in higher draught forces than the CV technologies, the specific draught of NSCT technologies were less across the three seasons showing that they were more energy efficient than CV technologies. As for efficiency and effective field capacity, NSCT methods performed better than the CV methods regardless of power source. This therefore means that farmers should choose NSCT methods.

## 6. Recommendations

The interminable rise in fuel prices will definitely impact negatively on the operating costs of tractors. Since tractor-drawn equipment is expensive and most smallholder farmers in the NCA use draught animals, it might be important to explore options that address the utilization of animal-drawn CT equipment. The use of animal-drawn implements could also limit the damage and compaction caused by tractor wheels during land preparation or weeding. It is therefore recommended that further research be carried out to test the combination in which a tractor-drawn ripper-furrower (TRF) is used to make furrows and break the plough pan in the first year, and an animal-drawn ripper-furrower (ARF) is used in subsequent years. The research can be used to establish the effectiveness of the combination and how often it would be necessary to return to tractor-drawn ripper–furrower use.

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