Volume 4, 1996

JOURNAL OF AGRICULTURAL ENGINEERING & TECHNOLOGY

Published by the Nigerian Society of Agricultural Engineers
and
Sponsored by the National Centre for Agricultural Mechanization, Ilorin

JOURNAL OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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Journal of Agricultural Engineering and Technology (1996), 4, 1-14

SPATIAL AND TEMPORAL VARIATION OF SOIL ERODIBILITY

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ABSTRACT

This paper reports on a study conducted under natural rainfall conditions to experimentally quantify the variability of the soil erodibility factor. Three erosion plots, each 2.44m wide and 4.88m long, on 8% slope (bare cover), were used for the experiments. Rainfall, runoff and sediment data were taken after each rainfall event during the 1993 rainy season, and parts of 1994 and 1995 rainy seasons. Soil erodibility computations were made using the original Universal Soil Loss Equation, USLE (K) and a revised USLE (K_m) that involved the inclusion of a runoff component in the erosivity factor.

The results reinforced the fact that soil erodibility varies spatially and temporally. Using the original USLE, the mean erodibility values (t.ha.hr/ ha MJ mm) obtained were 0.560, 0.052 and 0.032 for the 1993, 1994 and 1995 study periods, respectively; while the corresponding values using the revised USLE were 0.260, 0.025 and 0.016. For K, greatest variability was exhibited in May 1993, October 1994 and June 1995 with coefficient of variation (C.V.) values of 1.769, 1.208 and 0.953, respectively while for K_m greatest variability was exhibited in September 1993, October 1994 and April 1995 with C.V. values of 2.280, 0.963 and 0.833 respectively. In most cases, lower variability was obtained in K_m values (than in K), suggesting a lower degree of uncertainty associated with the use of the revised USLE. Monte Carlo simulations were conducted using the lognormal, exponential and normal probability distributions with the observed erodibility data as inputs. The exponential distribution best characterized the soil erodibility factor.

KEYWORDS

Soil erodibility.

1. INTRODUCTION

Soil erosion, a process of detachment and transportation of soil particles by wind or water, is a common problem in many parts of the world. While wind erosion may be of concern in some areas, water erosion is of greater concern in most parts of the world. Erosion and associated processes result in reduction in agricultural productivity, stream pollution, sedimentation and loss in reservoir capacity, ecological problems and general environmental degradation (Beasley et al., 1980; Tubbs and Haith, 1981; Ogunlela, 1989), each problem requiring a huge amount of money to solve.

Soil erosion studies may be conducted by experimentation or modeling. Such studies are usually beclouded by uncertainties in the values and forms of the parameters involved – due to their spatial and temporal variability. The Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1965, 1978) is an empirical erosion equation used in estimating soil loss from an area (usually agricultural lands). Over the years, the USLE has been used successfully to estimate the average, long-term soil loss from an area. However, its shortcomings have been identified as follows (Foster and Wischmeier, 1974; Foster, 1982; Foster et al., 1982a). The USLE does not estimate soil loss form single storms. It does not account for deposition within the watershed, and it lumps rill and interrill erosion together. This had led to various modifications of the original USLE (e.g. Foster and Wischmeier, 1974; Williams, 1975; Foster et al., 1977 and Foster, 1982) to improve on its predictive capabilities.

Soil erodibility, an important parameter in the erosion process, is a highly variable factor. It is influenced by moisture content, and soil properties such as density, structure, inter-particle cohesion, organic matter content, porosity and permeability (Middleton, 130; Wischmeier and Mannering, 1969; Wischmeier et al., 1971; O'Keefe, 1974; Morgan, 1979; Aneke, 1991), which interact in a complex manner in their effects on erodibility. Many researchers (e.g. Hudson, 1982, Foster et al., 1982b) have stressed the need for fundamental research on erodibility. De Vleeschauwer et al., 1978; Aina et al., 1980; Rubio-Montaya and Brown, 1984; Vanelslande et al., 1985; Mbagwu, 1986; Liebenow et al., 1990 and Aneke, 1991 have used various methods to estimate soil erodibility, including raindrop technique, static laboratory method, and the use of different indices. Dickinson et al. (1982) used Wischmeier's nomographic method (Wischmeier et al., 1971), laboratory rainfall simulator studies and soil shear strength measurements to estimate seasonal erodibility values.

In a study conducted on two loam soils for two consecutive years using rainfall simulation, Alberts et al. (1986) found that year was generally a highly significant source of variation in the erodibility values obtained. Mutchler and Carter (1983) expressed average monthly soil erodibility as a product of the USLE erodibility factor and a variability coefficient, expressed as a cosine function. The above-mentioned researchers also indicated the need for further research in this area of study.

The primary objective of this work is to experimentally quantify the variability of the soil erodibility factor. Associated with this objective is the determination of the extent of variability of the erodibility factor, and hence its degree of uncertainty – as a means of recognizing uncertainty in soil erosion studies. The secondary objective is to determine the extent of differences in soil erodibility values estimated using the original USLE and a revised USLE.

2. MATERIALS AND METHODS

2.1 Experimental Layout and Data Collection

This study was conducted during the 1993 rainy season, and parts of 1994 and 1995 rainy seasons. Three erosion plots, each 2.44m wide and 4.88m long, were constructed on the Soil Erosion Experimental Plot of the Department of Agricultural Engineering, University of Ilorin, Ilorin, Nigeria (longitude 4^{o} 35'E, latitude 8^{o} 3' N, Figure 1). The slope of each plot was 8%, on bare soil cover. Each plot was also bounded with sheet metals 1mm thick and 0.6m high, and equipped with a drum at the outlet for runoff collection.

The sheet metal at the upper end of each plot and the two at the sides were driven 0.15m into the soil while the sheet metal at the lower end of the plot was driven 0.45m into the soil. The lower end sheet metal was cut 0.15m wide in the middle, and a metal channel was welded into this opening to convey runoff from the plot into the collecting drum. Between two adjacent plots, a 0.9m walkway (on 8% slope) was provided to prevent water accumulation around the plot borders. The walkways also facilitated easier access around the plots to avoid interference with the plots.

Laboratory tests on samples of the soil used in the study indicated that the soil was sandy loam with 79.6% sand, 10% silt and 10.4% clay; and also with a pH of 7.2 and "rapid" permeability. The soil had 24.6% aggregates > 2mm, 2.14% organic C, and the following in meq/100g soil: Ex. Acidity (0.4), Ca (18), K (0.71), Mg (1.0), Na (0.23), ECEC (3.24).

Rainfall, runoff and sediment data were taken after each rainfall event. Three standard (non-recording) rain gauges, located around the plots, were used in measuring the rainfall amount, and the rainfall duration was determined by a watch. For each plot, the runoff and sediment from each storm were collected in a covered, 0.9m high, 0.57m diameter drum located at the plot outlet in soil excavated to 0.9m depth. The collected sediment was then oven-dried for soil loss determination. At the experimental site; 44 runoff-producing rainfall events were recorded between May 25 and October 24, 1993; 21 between July 21 and October 29, 1994; and 8 between March 22 and July 3, 1995. Also, no measurable runoff was recorded at the experimental site in May 1995.

2.2 Theoretical Development

2.2.1 Universal Soil Loss Equation

The Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1965 and 1978) is given as:

$$A = RKLSCP \qquad (1)$$

where: A = soil loss per unit area
R = erosivity factor
K = soil erodibility factor
L = slope length factor
S = slope-steepness factor
LS = topographic factor
C = cover-management factor
P = support practice factor

For a revised USLE, equation (1) could be re-written as:

$$A = R_m K_m LSCP \qquad (2)$$

where R_m is a modified erosivity factor and K_m is the corresponding soil erodibility factor. For the experimental design in this study (4.88m length on 8% slope, bare cover), the USLE factors were determined as LS = 0.4 (from charts), C = 1 and P = 1 (for bare cover and no conservation practice). Substituting these values into equations (1) and (2),

$$A = 0.4RK \qquad (3)$$

$$A = 0.4R_m K_m \qquad (4)$$

Equations (3) and (4) denote the original and revised USLE, respectively applied to this study. From these equations the soil erodibility factors for the original and revised USLE are computed as in Equations (5) and (6), respectively.

$$K = A/\,0.4R \qquad (5)$$

$$K_m = A/\,0.4R_m \qquad (6)$$

R is given as (Wischmeier and Smith, 1965 and 1978).

$$R = EI_{30} \qquad (7)$$

Where E is the total storm energy and I_{30} in the storm's maximum 30-minute intensity. Equation (7) is approximated by Foster et al. (1982a) as:

$$R = EI_{30} \approx c'V_r I_{30} \qquad (8)$$

where c' is a coefficient (c' = 1) and V_r is the rainfall depth. Foster et al. (1977) modified the R-factor in USLE to obtain an improved erosivity factor for a single storm, given as:

$$R_m = R_{rainfall} + R_{runoff} \qquad (9)$$

$$R_m = aEI_{30} + bV_u Q_p^{\,d} \qquad (10)$$

where: V_u = runoff depth
Q_p = peak runoff
a = 0.5, b ≈ 0.35, d ≈ 1/3 for V_u in mm and Q_p in mm/hr.
a, b and d are constants.

Foster et al. (1982a) approximated the peak runoff as:

$$Q_p \approx \alpha I_{30} \qquad (11)$$

(Lal, 1979), 0.48 in Eastern Nigeria (Niger Techno, 1975) to 0.535 in some parts of Northern Nigeria (Vanelslande et al., 1985). Mutchler and Carter (1983) obtained average annual USLE K values of 0.0328 and 0.0652 t.ha.hr/ha.MJ.mm for two locations, with erodibility ranging from 31% to 160% of the average annual K values. Other factors must have played dominant roles in these other studies.

In this study, for both K and K_m, the mean erodibility values decreased from 1993 through 1995. This is due to the fact that the same set of plots was used throughout the study. Each subsequent rainfall washes away the finer soil particles thereby exposing the less erodible coarser particles.

The variability of K and Km is equally evident when examined on a monthly basis. Moderate differences exist in the mean K and Km values. In most cases, the mean values of Km are lower than those of K. This is attributable to the inclusion of the runoff component in Km estimation. Runoff action dominates soil particle detachment and transportation in rill erosion. Thus, the inclusion of a runoff component in erosivity and erodibility estimation is especially important in situations where the number of rills is significant. Highest mean values of K were obtained in July 1993, July 1994 and June 1995 while the highest mean values of km were obtained in September 1993, July 1994 and March and June 1995. Plot 2 had higher mean erodibility values than Plots 1 and 3, in most cases.

For K, greatest variability was exhibited in May 1993, October 1994 and June 1995 with coefficient of variation (C.V.) values of 1.769, 1.208 and 0.953, respectively. For K_m, greatest variability was exhibited in September 1993, October 1994 and April 1995 with C.V. values of 2.280, 0.963 and 0.833 respectively. In most cases, lower C.V. values are oibtained for K_m than for K. This implies lower variability in K_m values, on the average, and suggests a lower degree of uncertainty associated with K_m values.

3.2 Probability Distribution of the Soil Erodibility Factor

For all the simulation experiments, the means of generated mean erodibilities and the observed mean erodibilities were very close, with absolute difference ($\Delta_{\bar{x}}$) ranging from 4.414×10^{-7} to 0.0133 t.ha.hr/ha.MJ.mm. The mean squared error (MSE) statistic, being a combination of the bias and variance of the estimator, was used as the judgement criterion for the selection of the best analysis option for each set of runs. The mean squared errors are shown in Table 2, ranging in magnitude from 0.66×10^{-6} to 5153.08×10^{-6} $(\text{t.ha.hr/ha.MJ.mm})^2$. The highest MSE values were obtained for the K93 (1993 K) data set while the lowest values were obtained for the KM95 (1995 K_m) data set.

For each simulation experiment and run data set the analysis option with the lowest MSE is shown in Table 3. The Analysis Option Frequency (the number of times each analysis option has the lowest MSE) is shown in Table 4. The purely stochastic exponential (EXP) analysis occurred the most frequently, excelling 45 times out of 90 (50.0%). This was followed by the mean + normal (MN) analysis which excelled 29 times out of 90 (32.2%) and the purely stochastic lognormal (LN) analysis which had the lowest MSE 16 times out of 90 (17.8%). The exponential distribution was thus chosen as the most adequate to characterize the soil erodibility factor. This implies, from the shape of the exponential density function, that the probability is high that the soil erodibility factor will assume a relatively small value; and also that the probability decreases as the erodibility value increases. This is consistent with soil erosion principles as, for a particular soil, extremely high erodibility values are relatively infrequently encountered. Such high erodibility values are usually associated with highly susceptible (to erosion) soil conditions under severe rainfall-runoff actions. The average susceptibility of any particular soil to erosion is usually reflected in its mean erodibility value which is used as input in the exponential distribution generator. The actual susceptibility to erosion at any particular time is influenced by the nature of the soil and cover, rainfall-runoff actions, slope length, shape and steepness and other topographic, hydrologic and hydraulic factors. The exponential distribution has also been used to represent hydrologic variables such as rainfall amount (Delleur et al., 1989).

A probabilistic representation of the soil erodibility factor, as obtained in this study, enables for example, the evaluation of the probability that soil erodibility values lies in some specified range, using the exponential cumulative distribution function. This could be extended to a probabilistic estimation of soil loss using an erosion equation such as the Universal Soil Loss Equation (USLE) or its revised version – for more effective erosioh prediction and control.

4. CONCLUSION

Soil erodibility was estimated using the original Universal Soil Loss Equation, USLE (K) and a revised USLE (K_m) – with an aim to experimentally quantify thee variability, and determine the extent of variability and the extent of differences in K and K_m. The mean, standard deviation, coefficient of variation (C.V.); minimum, maximum and range of K and K_m values were computed. The results reaffirmed the fact that soil erodibility varies spatially and temporally. Mean erodibility values decreased from 1993 through 1995 and moderate differences existed in the mean K and K_m values. In most cases lower erodibility and lower C.V. values were obtained when the revised USLE was used. The lower C.V. values for K_m suggests a lower degree of uncertainty associated with the use of the revised USLE in erodibility estimation.

Computer simulations were conducted using observed erodibility data and the lognormal, exponential and normal probability distributions – with an aim of selecting the most appropriate distribution for generating soil erodibility data. The lognormal and exponential distributions were used in the purely stochastic analyses while the normal distribution was used in generating the random component in the semi-stochastic analysis which had the mean erodibility value as its deterministic component. The mean squared error (MSE) statistic was used as the judgement criterion and the analysis option with the lowest MSE was chosen as the best for each set of runs. The results indicated that the purely stochastic exponential (EXP) analysis excelled 45 times out of 90 (50.0%), followed by the Mean + Normal (MN) analysis which excelled 29 times out of 90 (32.2%) and the purely stochastic lognormal (LN) analysis which had the lowest MSE 16 times out of 90 (17.8%). The exponential distribution was thus chosen as the most appropriate to represent the soil erodibility factor. This will enhance soil erodibility data generation, the making of probability statements on soil erodibility estimates, and probabilistic estimation of soil loss – for improved erosion prediction and control. The results from this study also provide a researcher or project personnel with a "feel" for the degree of variability of erodibility values – to be incorporated in the planning and conduct of soil erosion studies.

NOTATION

C.V. = coefficient of variation
E = total storm energy
I = average rainfall intensity
I_{30} = maximum 30-minute rainfall intensity
K = soil erodibility factor (original Universal Soil Loss Equation, USLE)
K_m = soil erodibility factor (revised USLE)
Q_p = peak runoff
R = erosivity factor
R_m = modified erosivity factor
V_r = rainfall depth
V_u = runoff depth

$$\alpha = \left(\frac{V_u}{V_r}\right)^{1/2}$$

n_r = approximate number of rainy days in a year
n_y = number of years of data being simulated
x = observed (untransformed) soil erodibility factor (K or K_m)
y = logarithmically transformed erodibility factor
x_o' = mean of observed (untransformed) erodibility

y' = mean of the logarithmically transformed erodibility, y
S_o = standard deviation of observed erodibility values
S_y = standard deviation of the logarithmically transformed erodibility, y
$C_{v,o}$ = coefficient of variation of observed (untransformed) soil erodibility
μ_x = population mean of x
σ_x = population standard deviation of x
σ_x^2 = population variance of x
μ_y = population mean of y
σ_y = population standard deviation of y
R_N = random number from a standard normal distribution
R_u = random number between 0 and 1
x_{rnor} = generatyed normal random number
x_{lrnor} = generated lognormal random number
x_{rexp} = generated exponential random number
$x_{g,i}'$ = mean of erodibility values generated for the ith year (generated mean erodibility for the ith year)
$S_{g,i}$ = standard deviation of erodibility values generated for the ith year
$C_{v,gi}$ = coefficient of variation of erodibility values generated for the ith year
x_g'' = mean of generated mean erodibilities
$S_{x,g}$ = standard deviation of generated mean erodibilities
$S^2_{x'g}$ = variance of generated mean erodibilities
$C_{v,x'g}$ = coefficient of variation of generated mean erodibilities
$\Delta_{,\cdot}$ = absolute difference between mean of generated mean erodibilities and observed mean erodibility
MSE = mean squared error.

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Table 1. **Spatial and Temporal Variability of the Soil Erodibility Factor (t.ha.hr/ha.MJ.mm)**

Year/ months	Plot(s)	No.	Min.	Max.	Range	Mean	Std. Dev.	C.V. *
1993 (May – Oct.)	K1	44	0.003	1.484	1.481	0.280	0.330	1.180
	K2	44	0.004	3.167	3.163	0.750	0.750	1.000
	K3	44	0.008	3.276	3.268	0.660	0.640	0.970
	K 1, 2 & 3	132	0.003	3.276	3.273	0.560	0.630	1.125
1993 (May – Oct.)	K_m1	44	0.005	0.511	0.506	0.506	0.130	1.000
	K_m2	44	0.008	1.048	1.040	0.380	0.680	1.790
	K_m3	44	0.015	0.965	0.950	0.280	0.220	0.786
	K_m 1, 2 & 3	132	0.005	1.048	1.043	0.260	0.430	1.650
1994 (July – Oct.)	K1	21	0.002	0.350	0.348	0.059	0.089	1.508
	K2	21	0.005	0.251	0.256	0.054	0.060	1.111
	K3	21	0.006	0.172	0.166	0.042	0.047	1.119
	K 1, 2 & 3	63	0.002	0.350	0.348	0.052	0.067	1.288
1994 (July – Oct.)	K_m1	21	0.002	0.120	0.118	0.026	0.028	1.077
	K_m2	21	0.004	0.073	0.069	0.027	0.021	0.778
	K_m3	21	0.005	0.065	0.060	0.023	0.017	0.739
	K_m 1, 2 & 3	63	0.002	0.120	0.118	0.025	0.023	0.920
1995 (March – July)	K1	8	0.002	0.099	0.097	0.029	0.032	1.103
	K2	8	0.008	0.084	0.076	0.032	0.024	0.750
	K3	8	0.002	0.135	0.133	0.034	0.043	1.265
	K 1, 2 & 3	24	0.002	0.135	0.133	0.032	0.032	1.000
1995 (March – July)	K_m1	8	0.003	0.034	0.031	0.016	0.011	0.688
	K_m2	8	0.010	0.031	0.021	0.018	0.007	0.389
	K_m3	8	0.002	0.028	0.026	0.015	0.008	0.533
	K_m 1, 2 & 3	24	0.002	0.034	0.032	0.016	0.009	0.563

* C. V. – Coefficient of Variation

Table 2*. **Mean Squared Errors, MSE (x 10^6)** (t.ha.hr/ha.MJ.mm)^2**

Sim.	K93			KM93			K94			KM94			K95			KM95		
Expt. #	LN	EXP	MN	LN	EXP	MN	LN	EXP	MN	LN	EXP	MN	LN	EXP	MN	LN	EXP	MN
1	4368.74	2633.84	4808.24	1758.99	588.45	2030.62	43.42	29.33	40.25	4.59	6.58	5.85	9.13	9.63	8.65	1.02	2.68	0.98
2	4029.44	2850.49	3360.41	1727.33	776.69	1783.82	49.56	25.03	54.95	5.87	6.50	5.84	10.41	8.82	10.18	0.97	2.29	0.69
3	4661.73	2962.68	4643.97	2000.99	613.93	1455.41	44.30	25.89	37.39	4.81	7.56	5.25	10.97	11.18	11.72	0.74	2.34	0.79
4	3225.04	3051.70	3813.57	1613.99	649.54	1684.76	51.51	22.10	32.87	5.93	6.47	5.94	8.65	8.33	12.63	0.88	2.68	0.69
5	3645.17	3634.28	3587.94	1763.67	878.46	2090.13	47.90	24.64	43.92	5.32	8.00	4.07	9.82	11.27	10.20	0.71	2.60	0.79
6	3398.73	2614.34	4747.55	1501.04	898.48	1945.81	42.95	34.06	31.08	6.60	7.36	5.62	7.71	7.58	9.21	0.93	2.66	1.04
7	4325.57	2637.30	4362.68	1739.63	666.46	2569.06	50.56	28.70	62.54	6.72	6.86	5.10	11.17	12.84	8.62	0.88	2.31	0.79
8	3460.56	2278.74	3433.65	2105.39	597.04	1778.40	40.01	26.71	40.83	5.23	6.15	5.16	8.37	12.10	9.81	0.94	2.92	0.89
9	4422.74	3881.85	3760.32	1469.99	678.12	1446.79	39.90	26.73	46.38	6.68	7.23	5.12	10.96	10.14	10.10	0.94	2.98	0.85
10	3645.26	3560.99	5060.32	1678.21	717.63	2253.70	35.94	29.23	34.28	6.53	6.00	5.29	12.71	10.19	10.16	0.86	2.09	0.67
11	4728.53	3264.31	2857.40	2491.42	541.73	1799.66	50.22	27.74	43.09	5.54	6.65	5.37	9.41	9.36	9.85	1.03	2.66	0.85
12	5153.08	3711.30	4474.10	1905.86	702.24	2177.08	51.10	25.13	45.34	5.19	6.24	5.50	11.08	10.46	10.45	0.76	2.87	0.79
13	5024.36	2679.24	4627.44	3204.37	677.11	2744.98	54.00	24.68	41.61	4.50	6.69	6.30	11.60	10.74	10.58	0.91	2.73	0.66
14	3738.24	3211.17	3550.47	2125.23	616.66	2189.90	43.06	29.23	48.52	4.93	7.83	4.77	11.44	9.94	10.33	0.86	3.28	0.71
15	3806.59	2503.37	4348.59	1690.22	710.87	2041.66	37.72	23.78	49.36	4.99	6.16	5.26	9.44	11.17	10.83	0.80	2.38	0.94

* K93, KM93, etc. = run data sets e.g. K93 = 1993 K data; KM95 = 1995 K_m data.
LN = lognormal (purely stochastic); EXP = exponential (purely stochastic); MN = Mean + Normal

** To obtain actual MSE, multiply by 10^{-6} e.g. 4368.74 x 10^{-6}, 0.98 x 10^{-6} (t.ha.hr/ ha.MJ.mm)^2

Table 3. Analysis Options with Lowest Mean Squared Errors (MSE)*

Sim. Expt. #	K93	KM93	K94	KM94	K95	KM95
1.	EXP	EXP	EXP	LN	MN	MN
2.	EXP	EXP	EXP	MN	EXP	MN
3.	EXP	EXP	EXP	LN	LN	LN
4.	EXP	EXP	EXP	LN	EXP	MN
5.	MN	EXP	EXP	MN	LN	LN
6.	EXP	EXP	MN	MN	LN	LN
7.	EXP	EXP	EXP	MN	MN	MN
8.	EXP	EXP	EXP	MN	LN	MN
9.	MN	EXP	EXP	MN	MN	MN
10.	EXP	EXP	EXP	MN	MN	MN
11.	MN	EXP	EXP	MN	EXP	MN
12.	EXP	EXP	EXP	LN	MN	LN
13.	EXP	EXP	EXP	LN	MN	LN
14.	EXP	EXP	EXP	MN	EXP	MN
15.	EXP	EXP	EXP	LN	LN	LN

* K93, KM93, etc. = run data sets e.g. K93 = 1993 K data; KM95 = 1995 K_m data.
LN = lognormal (purely stochastic); EXP = exponential (purely stochastic); MN = Mean + Normal

Table 4. Analysis Option Frequency (Number of Times Each Analysis Option has the Lowest Mean Squared Error, MSE*)

	K93	KM93	K94	KM94	K95	KM95	Total	% Total
LN	0	0	0	6	5	5	16	17.8
EXP	12	15	14	0	4	0	45	50.0
MN	3	0	1	9	6	10	29	32.2
							90	100.0

* K93, KM93, etc. = run data sets e.g. K93 = 1993 K data; KM95 = 1995 K_m data.
LN = lognormal (purely stochastic); EXP = exponential (purely stochastic); MN = Mean + Normal

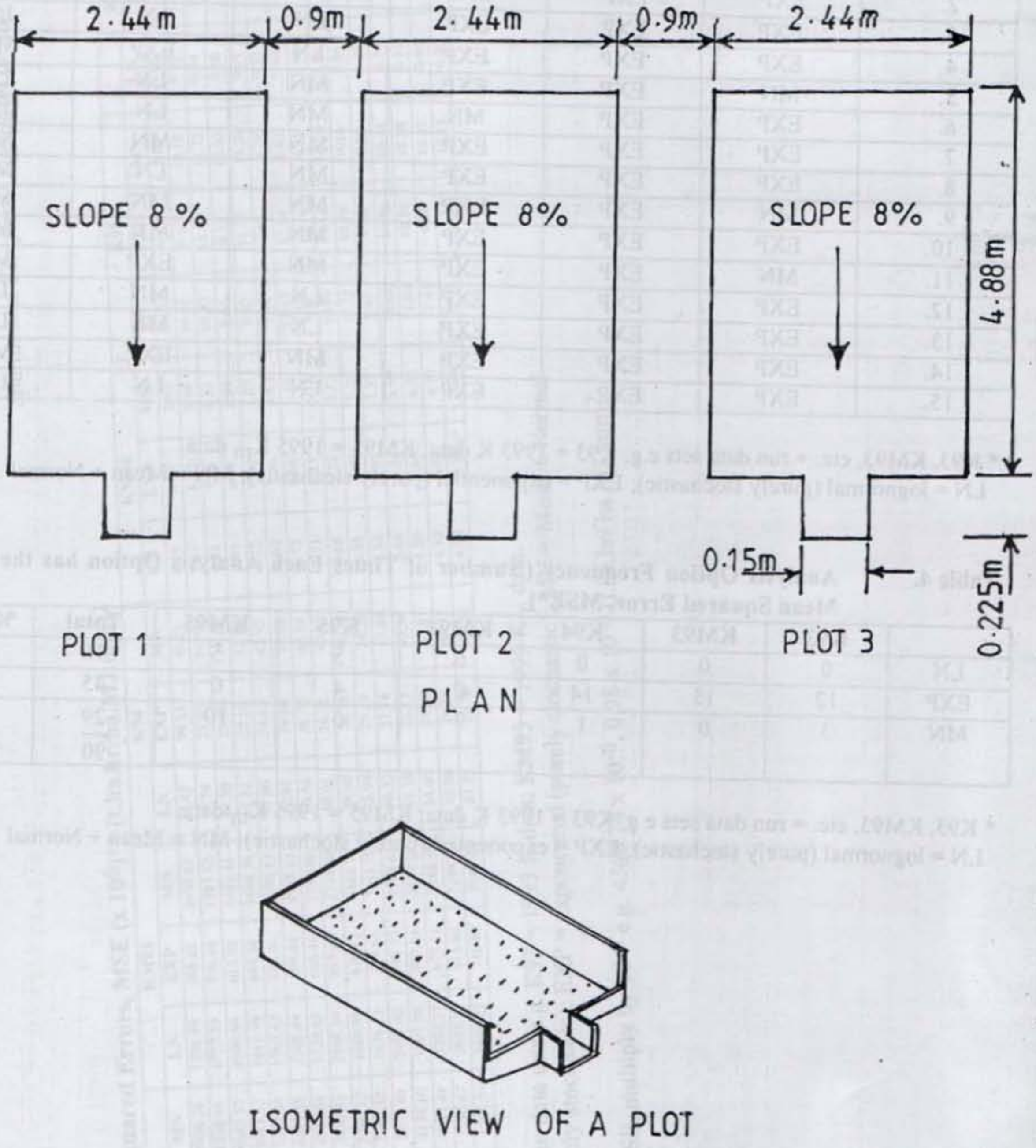

Fig. 1 Layout of soil erosion experimental plots

Journal of Agricultural Engineering and Technology (1996), 4, 15-28

USING INFRARED THERMOMETRY TO ESTIMATE GRAIN SORGHUM YIELD AND EVAPOTRANSPIRATION

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ABSTRACT

This study was carried out to evaluate the performances of canopy temperature (T_c) as indicator of plant water stress and to examine the relationship between T_c based stress indices and grain yield of sorghum. The crop was subjected to 14 differentially irrigated treatments of which two were controls maintained at well watered and dry conditions during three consecutive year. Soil water content, leaf water potential and canopy temperature were measured and relationships between T_c based stress indices (stress degree day SDD, Temperature stress day TSD) and yield as well as evapotranspiration were examined. Mid-day leaf water potential of a stressed plot varied from –1.1 MPa to –2.5 MPa while that of well watered pot did not descend beyond 1.8MPa. Predawn leaf water potential did not vary significantly between treatments. The canopy-air temperature varied from –2 to +8°C in stressed treatments and maintained a negative value for most of the time in well watered treatment. Although observations showed that both mid-day leaf water potential and T_c can be influenced by climatic conditions, this study confirms that they can serve as useful indicators of water stress in the case of sorghum. High correlation found between T_c based stress indices TSD and SDD and evapotranspiration as well as grain yield suggest their possibility for use for predictive properties.

KEYWORDS

Canopy temperature, Sorghum, Evapotranspiration, Radiothermometry.

1. INTRODUCTION

Grain sorghum, a crop of African origin, is known to be resistant to drought (Baldy et al , 1993) and) therefore a good alternative to maize when water is scarce.

Water deficit affects plant growth, metabolism and yield (Lewis et al, 1974). Accurate and timely determination of its effect on yield reduction is of great importance. Many research objectives have therefore been focused on finding easy and efficient methods of predicting yield of crops. Although different methods of yield prediction based on soil and plant measurements have been proposed, remote sensing of canopy temperature provides an enormous advantage (Idso et al, 1980). The simplicity, rapidity and the non-destructive nature of infrared thermometry measurement and the fact that it does not present sampling problem made it applicable to disease and insect damage assessment (Nicholas et al, 1991), plant water stress assessment (Jackson et al, 1981), irrigation scheduling (Clawson and Blad, 1982), and yield prediction of water stressed crops (Idso et al, 1977).Two canopy-temperature-based stress indices, the stress-degree-day (SDD) and temperature-stress-day (TSD) are simple to estimate and have been shown to relate well to yield (Gardner et al, 1981a, b; Diaz et al, 1983). The SDD concept was first developed by Idso et al, (1977), to estimate evapotranspiration (ET) and yields for a variety of irrigated crops. It is defined as:

$$SDD_i = (T_c - T_a)_i \qquad (1)$$

where T_c and T_a are midday canopy and air temperatures on day 1 (Idso et al, 1977).

The TSD index is estimated as the difference between midday canopy t.mperature of a crop and that of a well watered crop. That is:

$$TSD = (T_c - T_{cw})_i \qquad (2)$$

where T_c and T_{cw} are canopy temperatures of a crop and tat of a well watered crop respectively. A well watered plot (i.e. at evapotranspiration maximum) is thus required to estimate this index. It is important to note that these indices require few measurements unlike other temperature based indices such as crop water stress index (CWSI) which may require solar radiation, vapour pressure and wind measurements in addition to temperatures.

Gardener et al. (1981a) who correlated the yields of two hybrids of sorghum (*Sorghum bicolor L*) grown under several irrigation regimes with TSD, used a single planting date. Idso et al. (1890) showed that planting dates and climatic variability has effect on the relationship between yield and ΣSDD and therefore proposed the introduction of solar radiation. Diaz et al, (1983) who performed their experiments on wheat therefore introduced the incoming radiation at vegetative stage to account for difference in planting dates. These studies were carried out in the arid regions of USA under climatic conditions very different from that of France. Although infrared thermometry (IR) seems promising in Southern France particularly for irrigation scheduling of sorghum (Olufayo et al. 1993a) it would be necessary to establish its limits before going into practical application. This study which is part of a research project on irrigation management of sorghum and soyabean, is aimed at examining the relationship between canopy temperature-based indices (requiring only temperature measurements i.e. TSD and SDD) and evapotranspiration and grain yield. Several planting dates of grain sorghum (subjected to drought stress at various stages of growth) were used to reveal any time variation or time trends in these relationships. Other measurements such as leaf water potential and phenological development are considered.

2. MATERIALS AND METHODS

Grain sorghum (sorghum bicolor (L) Moench) cv. Argence was grown in a deep loamy clay soil at "the French Institute of Agricultural and Environmental Engineering Research – (CEMGREF)" experimental station Lavalette, in Montpellier (France) (43° 40'N, 3° 50'E). The experimental site covers about 2 hectares and consists of deep loamy soil. The crop was sown on 3 May 1990, 16 May 1991and 7 May 1992 at 0.5m spacing between rows. Fertilizers (NPK) were applied prior to planting at the rate of 150g/ha N and 100kg.ha of P_2O_5. Plant population varies between 200,000 to 300,000 plants per hectare.

There were 14 treatment plots altogether during the three years of study (Table 2). They were maintained at different levels of irrigation regime based on crop developmental growth periods defined in Table 2 using Vanderlip and Reeves (1972) phenological scale. Each treatment plot was about 24m by 48m in size. These big sized pots were preferred in order to minimize experimental errors due to interference between neighbouring microclimates. Previous study in this field showed that the soil is homogeneous.

Soil moisture content was monitored twice a week using a neutron probe at intervals of 10cm until about 3m soil depth. An access tube was installed at the centre of each experimental plot. A series of tensiometers at 10, 20, 30, 40, 60, 90, 100, 120, 140, 160 and 180cm soil depth were also installed at the centre of each treatment plot. Evapotranspiration for each treatment was estimated using the water balance technique between soil surface and plane of zero flux (Vachaud et al., 1978).

Leaf water potential was determined at predawn and at mid-day using a pressure chamber (Scholander et al., 1965). The pressure chamber accurately estimates the leaf water potential of sorghum. Measurements were carried out on penultimate leaves of six selected plans characterizing the degree of stress of the entire canopy of each plot. An arithmetic average was thus computed.

Canopy temperature readings were taken using a hand-held infrared thermometer (Tasco THI 300)[1]. The spectral band-pass of the instrument was 6 to 12mm with a resolution of 0.1oC and a field of view of 10o. Other IR thermometers used were Raytek (model Raynger PM3), and Everest 110 and 510B. Measurements were taken at an oblique angle to avoid sensing soil temperatures and also by viewing sunlit leaves. The data averaging feature of the infrared thermometer was employed to reduce variability in canopy temperature. At least 10 readings were taken at the centre of each treatment plot and an arithmetic average

[1] Mention of a trade name does not imply endorsement of the product or company.

was computed. Canopy temperatures were monitored at each bright sunny day between 11h30 and 13h30 solar time. The instruments' calibrations were checked in a laboratory prior to start of experiments and systematic re-calibrations were carried out in the field during experiments (Olufayo et al., 1993b). Both canopy temperature and leaf water potential measurements began when leaf area index (LAI) was about 2 (when the ground was well covered so as to avoid taking measurements of soil's surface) and ended at about an LAI of 5 (at physiological maturity). A standard meteorological station (CIMEL 411, France) is situated at 120m from the experimental site. It furnishes hourly and/or three hourly as well daily averages of air temperature T_a, relative humidity RH, wind speed and solar radiation which are necessary for the estimation of potential evapotranspiration using Penman formula. In addition a portable electronic thermohygrometer (CORECI, France) was used to measure T_a and RH at 10cm above crop canopy within the experimental plots. Sunshades were utilized to minimize direct sun-ray incidence on the sensors.

Each plot was sprinkler irrigated using a 12m by 12m triangle arrangement. Irrigation water was applied at nights when wind speed was low (< 2m/s) to ensure even distribution. The required irrigation amounts per application were based on water balance model estimates of the current root zone available water depletion (see Table 2). Irrigation amounts allowed about a 13mm unfilled root zone storage capacity for small rainfalls that might occur soon after an irrigation event.

Visual phenologic and crop height observations were made at weekly intervals to document growth stage development. Yields were standardized to 15% d.b. moisture. Panicles were harvested by hand and shelled mechanically.

3. RESULTS AND DISCUSSIONS

3.1 Seasonal Evolution of Leaf Water Potential and Canopy-Air Temperature Difference

Since weather conditions affect both surface temperature and leaf water potential measurements (Gardner et al., 1981a), it is necessary to describe the climatic conditions prevailing during the period of experiments. The growing season for sorghum extends from May to September. As shown in Fig. 1 for 1991, the climate is characterized by the warm, clear day and dry conditions having relatively high evaporative demand (4 to 7 mm/day) during the early growth stages through dough stages. During hard dough through physiological maturity, it is characterized by cooler day and wet conditions with relatively low evaporative demand. However, substantial variation was observed from year to year. For example total precipitation from the month of May to August is 100mm in 1990, 130mm in 1991, and 280mm in 1992. The summer of 1992 was particularly wet and the annual precipitation exceeded the 30-year average value (750mm out of which 110mm fall in summer). The seasonal trends of leaf water potential and canopy-air temperature difference ($T_c - T_a$) of a stressed and well watered treatments in 1990 are shown in Fig. 2. Predawn leaf water potential were not significantly different between treatment. In the most stressed plot, its average values varied between –0.2Mpa to –0.6Mpa throughout the season. The changes in the value of mid-day leaf water potential throughout the season are more pronounced; it varied from –1.2Mpa to –2.5Mpa from 48 days after sowing (DAS) to 80 DAS in a stressed plot. The canopy-air temperature difference fluctuated but increased progressively during this period when there was no rainfall or irrigation. The fluctuations are due to daily variations of climatic parameters. Both mid-day leaf water potential and $T_c - T_a$ were affected by rainfall. Variations within the plot were greater in their values during and after rainfalls at period III (Table 2) as shown by standard variations in Fig. 2.

A crop water stress index which was defined by Jackson et al. (1981) requires the establishment of a "non-water baseline" which is a relationship between $T_c - T_a$ and vapour pressure deficit (VPD) of a well watered treatment. This was carried out using 1990 and 1991 data. Two series of air temperature and VPD data were used. One concerned measurement taken at 10cm above canopy within the plot and the other came from the meteorological station. In all cases, high correlation in the linear relationship was observed. Details of this analysis were reported by Olufayo et al. (1993a). The following is the regression equation obtained using all data:

$$(T_c - T_a) = -1.88VPD + 4.00;\ n = 91,\ r^2 = 0.71 \qquad (3)$$

3.2 Yield Responses Relationships

A T-test analysis was performed to compare average grain yield per plot with that obtained near the neutron access tube. Both paired and independent tests showed that the two sets of data were not significantly different at 0.05. We therefore used only the grain yield data obtained near neutron access tube in establishing yield, Y versus seasonal evapotranspiration, ET (emergence to physiological maturity) relationships. The regression equations obtained are shown in Table 3. F-test described by Sherrer (1984) for comparing several slopes and intercepts were used to investigate the possibility of time variation in the yield-ET regression equations. The slopes were equivalent but the intercepts were found to be significantly different. However, on a relative basis, the F-test showed that the slopes as well as the intercepts..of regressions equations at the 2.5% level (see Table 4). The single relationship obtained for the combined (1990 and 1991) data gives:

$$Y/Y_m = 0.04ET - 1.01;\ r^2 = 0.91,\ S_{y/x} = 0.07 \qquad (4)$$

Where Y_m is the yield at maximum evapotranspiration, Y/Y_m is the relative yield and $S_{y/x}$ is the standard error of estimate y on x.

Average grain yield per slot was related to canopy temperature based indices. In estimating the summations of TSD and SDD only positive values of TSD and SDD were considered (Jackson et al., 1977). The period of summation for each year covers 50 days and lies between end of growth period II and period IV (see Table 2). The resulting regression equations are presented in Table 3. Both ΣTSD (Fig. 3) and ΣSDD are well correlated with yield ($r^2 > 0.87$). Grain yield decreased with increasing ΣTSD. Similar relationships were obtained when relative yield was used (Table 4). Unlike yield-ET relationship, thee is no effect of planting date on the regression coefficients (of Y-ΣTSD relationship) as indicated by the F-test analysis at the 0.05 level. This implies that if yield under unstressed condition is known, it is possible to estimate the grain yield as a function of ΣTSD values. This agrees with results reported by Gardner et al. (1981a) for two moisture stressed sorghum hybrids. Although yield is also highly correlated with SDD, statistical results of the F-test on the effect of planting dates showed that the slopes of the two equations were similar and the intercepts were significantly different (Table 3). Contrary to the results obtained by Diaz et al. (1983), the introduction of solar radiation did not account for the effect of planting date. However, when the relative yield basis was examined, statistical analysis showed that the two regression equations for the two planting dates were not significantly different at 0.05 level (see Table 4). It therefore appears that in our conditions climatic factors other than solar radiation influence this relationship. When the three treatment in 1992 were included in the analysis, the combined data resulted in the following relationship:

$$Y/Y_m = 0.004\Sigma SDD + 1.06;\ r^2 = 0.94,\ S_{y/x} = 0.049 \qquad (5)$$

where $S_{y/x}$ is the standard error of estimate y on x.

It is worth noting that the inclusion of the 1992 data did not affect the high correlation coefficient.

3.3 Relationship Between Seasonal Evapotranspiration (ET) and Stress Indices

The results showed that ET is linearly and inversely related to both TSD (see equations 6 and 7) and SDD (Fig. 4). Many works have shown similar results for various crops in many locations (Idso et al., 1977; Walker and Hatfield, 1979; Diaz et al., 1983). A slightly better correlation is obtained with ΣSDD ($r^2 = 0.95$ to 0.98) than with ΣTSD ($r^2 = 0.74$ to 0.93) in this study. Statistical analysis showed that ET-ΣTSD relationship is influenced by planting date unlike the Y-ΣTSD relationship. For 1991 and 1990 combined data, the following linear equation is obtained:

$$ET = -0.69\ \Sigma TSD + 468.7;\ r^2 = 0.70,\ S_{y/x} = 23.9 \qquad (6)$$

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Average grain yield per slot was related to canopy temperature based indices. In estimating the summations of TSD and SDD only positive values of TSD and SDD were considered (Jackson et al., 1977). The period of summation for each year covers 50 days and lies between end of growth period II and period IV (see Table 2). The resulting regression equations are presented in Table 3. Both ΣTSD (Fig. 3) and ΣSDD are well correlated with yield ($r^2 > 0.87$). Grain yield decreased with increasing ΣTSD. Similar relationships were obtained when relative yield was used (Table 4). Unlike yield-ET relationship, thee is no effect of planting date on the regression coefficients (of Y-ΣTSD relationship) as indicated by the F-test analysis at the 0.05 level. This implies that if yield under unstressed condition is known, it is possible to estimate the grain yield as a function of ΣTSD values. This agrees with results reported by Gardner et al. (1981a) for two moisture stressed sorghum hybrids. Although yield is also highly correlated with SDD, statistical results of the F-test on the effect of planting dates showed that the slopes of the two equations were similar and the intercepts were significantly different (Table 3). Contrary to the results obtained by Diaz et al. (1983), the introduction of solar radiation did not account for the effect of planting date. However, when the relative yield basis was examined, statistical analysis showed that the two regression equations for the two planting dates were not significantly different at 0.05 level (see Table 4). It therefore appears that in our conditions climatic factors other than solar radiation influence this relationship. When the three treatment in 1992 were included in the analysis, the combined data resulted in the following relationship:

$$Y/Y_m = 0.004\Sigma SDD + 1.06;\ r^2 = 0.94,\ S_{y/x} = 0.049 \qquad (5)$$

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$$ET = -0.69\ \Sigma TSD + 468.7;\ r^2 = 0.70,\ S_{y/x} = 23.9 \qquad (6)$$

where Sy/x is the standard error of estimate y on x.

The correlation becomes very poor when 1992 data is included:

$$ET = -0.37\ \Sigma TSD + 424.1;\ r^2 = 0.20,\ S_{y/x} = 38.7 \qquad (7)$$

Although the precise reason for this is not known, it appeared that the climatic diversity during experiments is partly responsible. As mentioned above, 1992 was described as being particularly wet. This would obviously modify the rate of water use by the crop. In addition, ET would be estimated less accurately in periods of excessive rainfall than if otherwise. On a relative basis and using all data (i.e. including 1992), the correlation was greatly improved.

$$ET/ET_{max} = -0.0014\ \Sigma TSD + 0.95;\ r^2 = 0.77,\ S_{y/x} = 0.04 \qquad (8)$$

Where ET_{max} is seasonal evapotranspiration in wet treatment (i.e. T1) for each year. Similarly, the inclusion of 1992 data reduced the coefficient of correlation (r^2) to 0.448 and on relative basis, $r^2 = 0.94$.

4. CONCLUSION

This study showed that mid-day leaf water potential and canopy temperature are useful indicators of water status in the case of sorghum under the Mediterranean condition prevailing in Montpellier, France.

Significant linear relationships were established between canopy temperature based indices and yield as well as evapotranspiration. This is of great importance since it suggests the possibility of estimating yield and evapotranspiration from canopy temperature data. This would be of great interest in Southern France for establishing an optimum irrigation strategy not only on a local scale since many improved models of portable radio-thermometers exist today in the market. On a regional scale, the use of satellite data (e.g. NOAA-6, TISOS-N, HCMM and METEOSAT) would allow large scale estimations of yield and evapotranspiration (Segiun and Itier, 1983).

Although this experiment was carried out in France, the experimental results obtained on sorghum would be useful in other parts of the world and especially in Africa, the crop's origin.

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Table 1. Growth Stages and Corresponding Periods of Development of Sorghum

Growth Stage	Definition (Vanderlip and Reeves, 1972)	Period	DAS #
0		I	
1	Collar of third leaf visible	Emergence	0 – 30
2	Collar of fifth leaf visible	Establishment	
3	Growing point differentiation (approx. 8 leaf stage)	II	30 – 60
4	Final leaf visible in whorl	Vegetative	
5	Boot head extended into flag leaf sheath	III	
6	Half-boom, half of plants at some stage of bloom	Reproductive	60 – 90
7	Soft dough		
8	Hard dough	IV	
9	Physiological maturity, maximum dry matter accumulation	Maturity	90 – 120

days after sowing (DAS)

Table 2. **Irrigation, Rainfall and Level of Stress at Different Growth Periods**

Treatment or Year	Level of Stress	Growth Period				Total Irrigation or Rainfall
		Period I	Period II	Period III	Period IV	
1990		Irrigation (mm)				
T1	NNNN	32	72	128	86	318
T2	NNNS	45	54	68	0	167
T3	NNSN	33	60	0	92	185
T4	NSNN	29	0	81	87	197
T10	NMSS	42	24	0	0	66
T11	NSSS	36	0	0	0	36
		Rainfall (mm)				
		51	21	25	0	97
1991		Irrigation (mm)				
T1	NNNN	78	60	104	102	344
T3	NNSN	78	50	0	57	185
T5	NSNS	82	0	50	0	132
T9	NMMM	80	30	31	40	181
T11	NSSS	78	0	0	0	78
		Rainfall (mm)				
		12	6	19	136	173
1992		Irrigation (mm)				
T1	NNNN	35	0	83	107	225
T7	NNSM	27	0	0	15	42
T11	NNSS	24	0	0	0	24
		Rainfall (mm)				
		120	106	5	22	253

Level of stress at different growth periods: N – no stress; M – moderate stress; S – severe stress.

Table 3. Linear Regression of Yield (y) vs. ET (x_1) Index (ΣTSD (x_2) and ΣSDD (x_3)) for Each Planting Date and F-test for Slopes and Intercepts

Date of Planting	A $kg/m^2/mm$ or $kg/m^2{}^oC$	b kg/m^2	r^2	$S_{y/x}$
	Evapotranspiration (ET) - (x_1)*			
3 May 1990	*0.004*	*-0.91*	*0.94*	*0.06*
16 May 1991	*0.004*	*-1.04*	*0.96*	*0.06*
F_{value}	*0.40*	*81.91*		
$F_{0.05}$	*5.32*	*5.32*		
	ΣTSD ** ($-x_2$)			
3 May 1990	-0.004	1.13	0.87	0.08
16 May 1991	-0.003	0.95	0.99	0.03
F_{value}	3.19	0.51		
$F_{0.05}$	5.32	5.32		
	ΣTSD ** ($-x_2$)			
3 May 1990	-0.005	1.19	0.95	0.08
16 May 1991	-0.004	0.96	0.98	0.02
F_{value}	1.79	36.75		
$F_{0.05}$	5.32	5.32		

* using yield data obtained near neutron access tube

** using average grain yield per plot

a, b and $S_{y/x}$ are slope, intercept and standard error of y (yield) on x_1, x_2 and x_3 respectively.

Table 4. Linear Regressions of Relative Yield, Y/Y_m (y) vs. ET (x_1) Index (TSD (x_2) and SDD (x_3)) for Each Planting Date and F-test for Slopes and Intercepts

Date of Planting	a kg/m²/mm or kg/m²°C	B kg/m²	r^2	$S_{y/x}$
	Evapotranspiration (ET)* - (x_1)			
3 May 1990	0.004	-0.77	0.94	0.05
16 May 1991	0.004	-1.16	0.96	0.06
F_{value}	1.06	7.04		
$F_{0.05}$	5.32	5.32		
$F_{0.025}$	7.57	7.57		
	ΣTSD ** ($-x_2$)			
3 May 1990	-0.005	1.13	0.87	0.08
16 May 1991	-0.003	1.05	0.96	0.04
F_{value}	2.12	2.40		
$F_{0.05}$	5.32	5.32		
	ΣTSD ** ($-x_2$)			
3 May 1990	-0.004	1.11	0.95	0.05
16 May 1991	-0.004	1.07	0.98	0.03
F_{value}	0.026	1.96		
$F_{0.05}$	5.32	5.32		

* using yield data obtained near neutron access tube

** using average grain yield per plot

a, b and $S_{y/x}$ are slope, intercept and standard error of y (yield) on x_1, x_2 and x_3 respectively.

Fig. 1

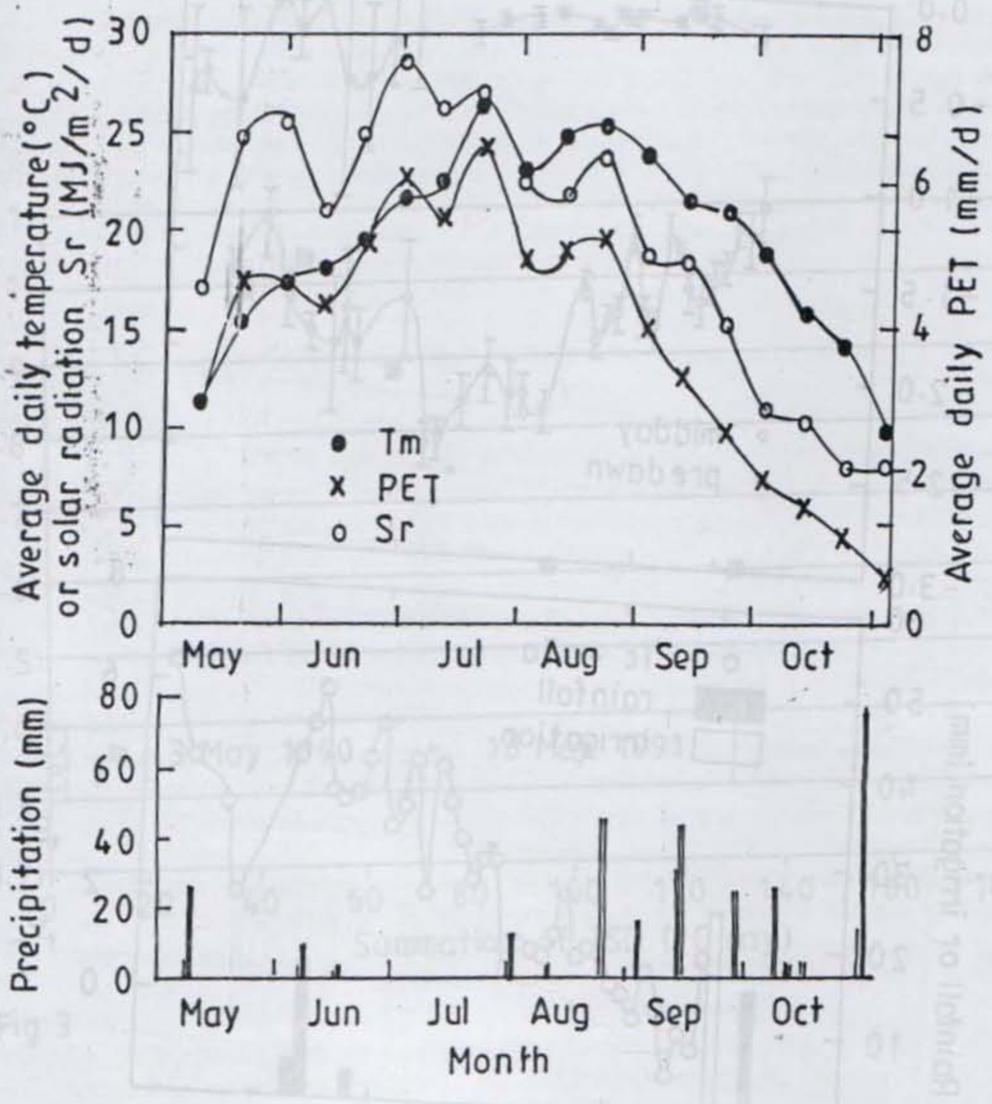

Fig.1 Precipitation average air temperature (Tm). solar radiation (Sr) and potential evapotranspiration (PET) for 10 days during the growing season

Fig. 2

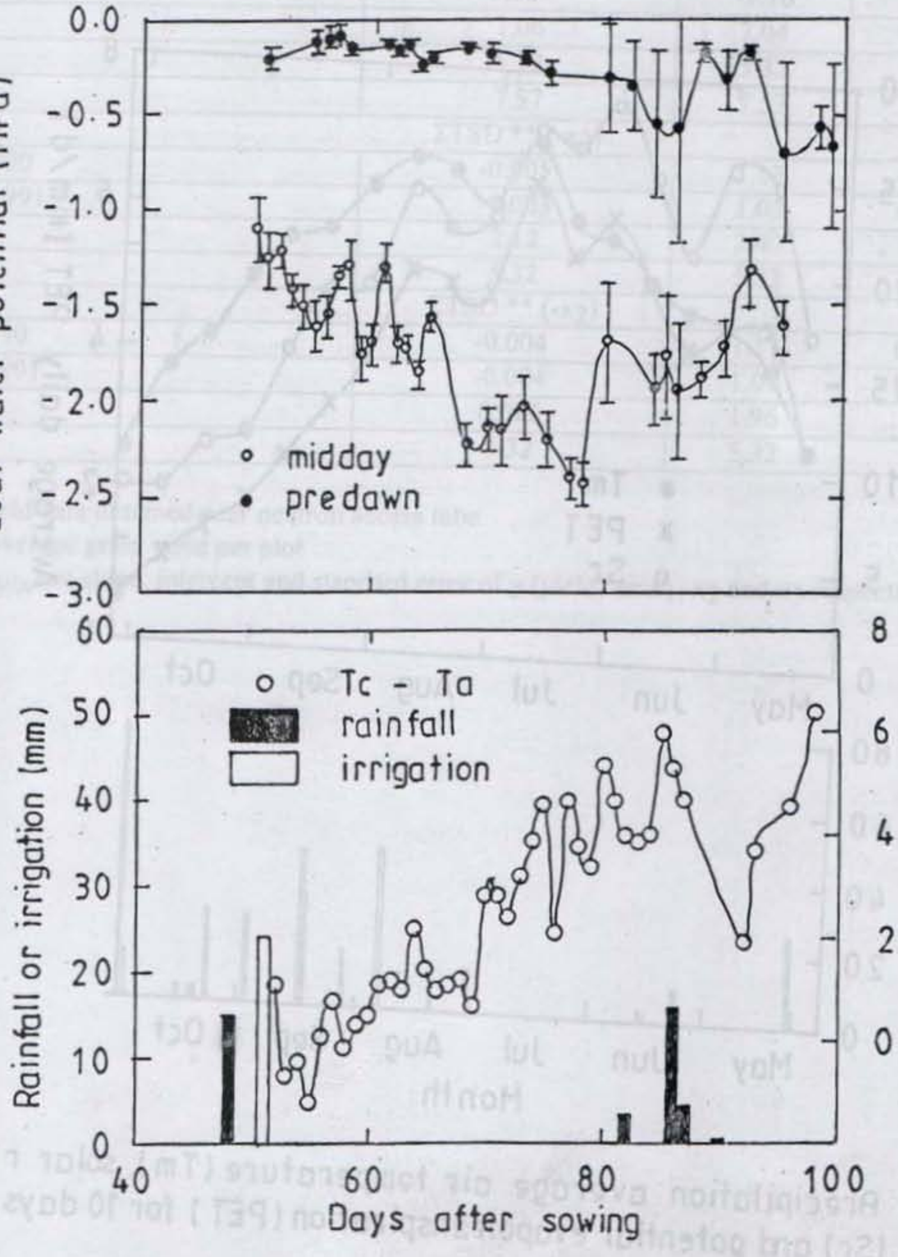

Fig. 2 : Rainfall, irrigation, and seasonal evolution of midday and predawn leaf water potential, canopy-air temperature difference (Tc – Ta) in a stressed treatment (T10)

Fig. 3

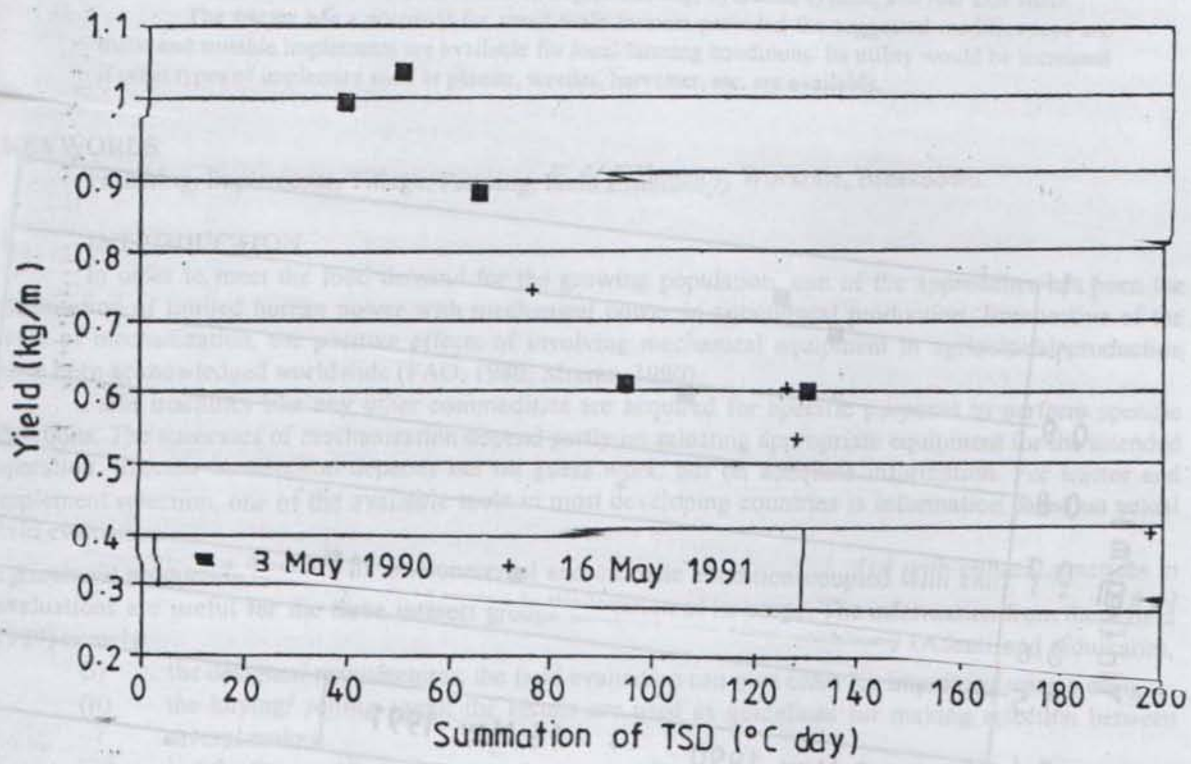

Fig. 3

Fig 3: Relationship between the yield and TSD

Fig. 4

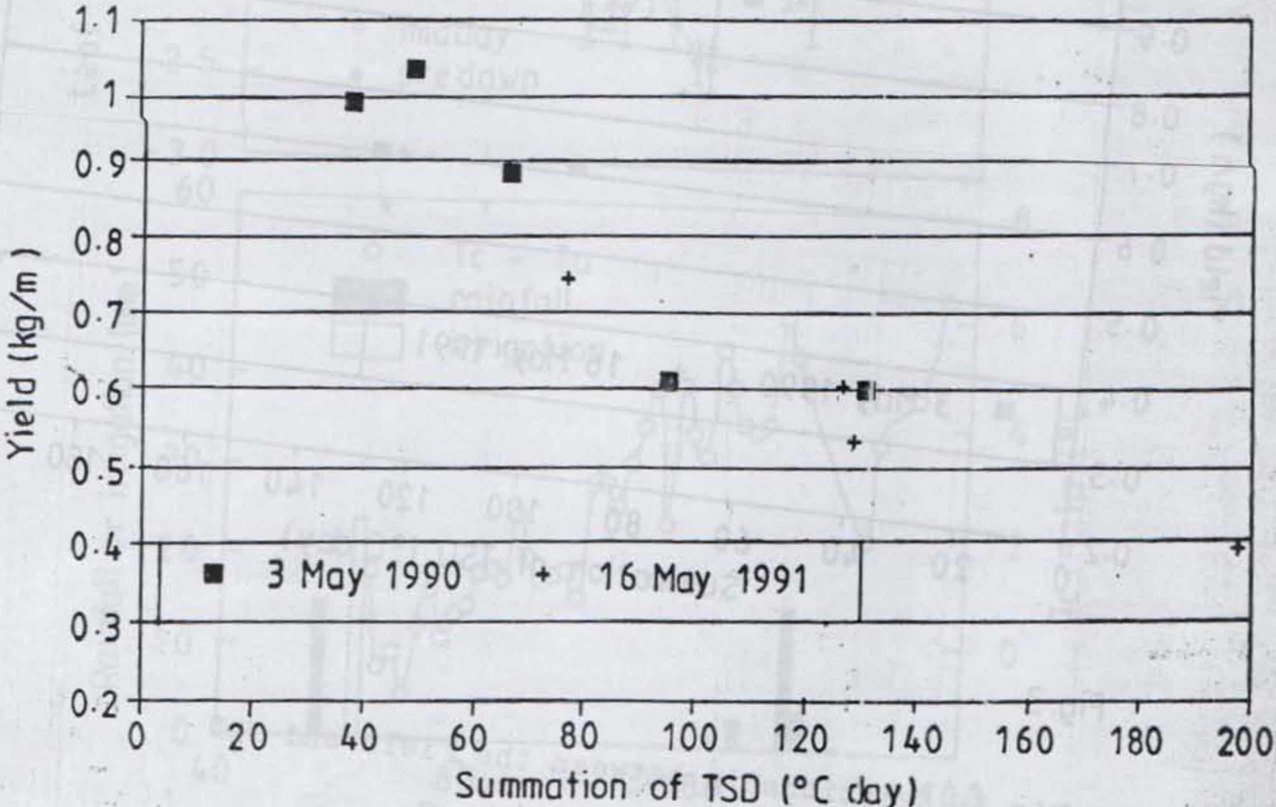

Fig. 3

FIG 4: Relationship between seasonal ET and SDD

Journal of Agricultural Engineering and Technology (1996), 4, 29-38

EVALUATION OF QM FARMKING 200 TRACTOR AND APPROPRIATE IMPLEMENTS UNDER LOCAL FARMING CONDITONS

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ABSTRACT

A QM Farmking 200 (16.8KW) tractor with six implements; namely disc plough, disc harrow, tine cultivator, disc ridger, mouldboard ridger and trailer, was tested on sandy-loamy soil in the Northern Guinea Savannah area of Nigeria. This was done with the objective of determining its suitability as a prime-mover for farming operations in the area.

The tractor performance was generally satisfactory with the equipment tested. For tillage operations, the tractor had an average overall field efficiency of 74 percent. The output varied from 0.07 to 0.67 ha/h and fuel consumption varied from 2.0 to 20.2 L/ha depending on type of operation, operating speed, and soil conditions. During the two rainfed farming seasons of its operation, there were breakdowns and operational difficulties. The tractor would thus need more modifications; these include improvement on engine starting, hydraulic system, and real axle shaft.

The tractor has a potential for small scale farmers provided the suggested modifications are made and suitable implements are available for local farming conditions. Its utility would be increased if other types of implemtns such as planter, weeder, harvester, etc. are available.

KEYWORDS

Farmking, Implements, Tillage, Farming, Field Efficiency, Workrate, Breakdown.

1. INTRODUCTION

In order to meet the food demand for the growing population, one of the approaches has been the substitution of limited human power with mechanical power in agricultural production. Irrespective of the level of mechanization, the positive effects of involving mechanical equipment in agricultural production have been acknowledged worldwide (FAO, 1980; Mrema, 1990).

Farm machines like any other commodities are acquired for specific purposes to perform specific functions. The successes of mechanization depend partly on selecting appropriate equipment for the intended operation. Success in selection depends not on guess work, but on adequate information. For tractor and implement selection, one of the available tools in most developing countries is information based on actual field evaluation.

Generally, the diversity of environmental and climatic condition coupled with cultural practices in agricultural production necessitates field testing in the location of its usage. The information from these field evaluations are useful for the three interest groups involved with farm machinery (Adeoti and Adulkarim, 1989) nemely:

(i) the designer/ manufacturer; the field evaluation can give clues for improving upon a design;
(ii) the buying/ selling agent; the results are used as guidelines for making selection between several makes;
(iii) and for the user/ farmer; the results are used for deciding on suitablility for his requirements.

More specifically, tractor testing is set up to protect the interest of local farming community. For example, the Nebraska Test was set up primarily to protect the interest of the Nebraska farmers against poor quality tractor being introduced into the state. Similarly, the British National Institute of Agricultural Engineering was set up to protect the British farmers (Sims, 1972). To date, farm machinery testing is being conducted in more than 20 countries by over 25 agencies (Adekoya, 1988).

In Nigeria, farm machinery testing is being carried out y several Agricultural Institutes and Agricultural Engineering Departments. Among them are the Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria; Department of Agricultural Engineering, Obafemi Awolowo University, Ile-Ife; National Centre for Agricultural Mechanization, Ilorin, etc.

Some of the basic factors necessary for the selection of tractors are reliability, durability, versatility, cost, performance, safety, accessories, appearance, make, and after sale services. Assuming that the tractor has passed the laboratory tests, the factors of specific relevance from users' view point are those relating to performance characteristics which are dependent on vegetation, soil types, soil state, climate, topography, farming systems, and types of farming operations which are location specific. In addition, there has to be the proper matching of power, weight, speed and slip to ensure optimum power transmission (Gee-Clough *et al.*, 1990).

A QM Farmking 200 tractor with a set of implements was supplied by NAMCO Nigeria Limited, Kano, a dealer; to be tested by the Institute for Agricultural Research (IAR), Samaru, Zaria, Nigeria. This is to determine the potentials and suitability of the tractor and the implements with resapect to the local farming conditions in the Northern part of Nigeria. The specific objectives of the work were:

(i) to evaluate the tractor and its implements during appropriate farming operations with respect to field condition, speed of operation, fuel consumption, work rate, and field efficency.

(ii) to assess the breakdown, wear, and operational difficulties during the field operation.

2. MATERIALS AND METHOD

The primary equipment for the tests were a QM Farmking 200 (16.8KW) tractor and six implements supplied by the dealers namely: disc plough (2-discs), disc harrow (2x6 discs), tine cultivator (4-harrow tines), disc rider (4 discs), mouldboard ridger (3-bottom) and tipping trailer. Figure 1 shows the tractor with one of the implements. The tractor is powered by a 1266cc, 2-cylinder direct injection, 4-stroke diesel engine. It has hand throttle and stop control. It has standard floating 3-pioint linkage to category I standard with top link category I or II mounting points and external chain type stabilizer. These are adaptable to a variety of 3-point hitch type tools. It also has a jaw-type removable drawbar mounted on its sub-frame.

Its other special features include the bench-type 2-person seat, manual starting and a 12 volts DC dynamo arrangement for light horn when its engine is running.

The following measuring instruments were used: tape, stop watch, tachometer, soil samples, oven, weighing scale, and graduated plastic jar. The test site was on a sandy-loamy soil at Samaru, Zaria which is situated within the Northern Guinea Savannah Zone and lies between latitude 9^{0}N and 13^{0} 15' N. The site included the Institute for Agricultural Research, Samaru, Zaria, experimental plots, as well as adjacent farmers' field. Some of these had been under continuous cultivation, while others were fallow. The tests were carried out for two fill-rain-fed farming seasons, that is, mid June 1987 to late October 1988, in order to expose the tractor and implements to a wide range of soil conditions for different tillage operations under rainfed farming in the locality.

The rainfall pattern for the locality for 1986 - 1989 is on Table 1. In the locality, rainfall generally establishes in late June, immediately followed by heavy douwnpours, resulting in water logged conditions. This limited period for optimum soil condition for tillage operations but offered the tractor and implements an exposure to adverse soil conditions. The report therefore covers performance over a wide range of operating soil conditions, which are realistic farming situations in the locality.

The selected parameters for assessing the performance of the tractor and the implements included soil moisture content, wheel slip, tractor speed, depth and width of cut, fuel consumption, work rate and field efficiency.

The tractor engine speed was controlled by a throttle lever. Since the tractor has no speedometer, it had to be calibrated in order to relate the engine speed to the throttle lever position. For calibration purpose, a hand held tachometer was used to monitor the engine speed. The throttle lever was pushed until the engine crankshaft reached the intended speed. The position of the throttle lever that gave this reading was marked.

The engine speeds that were found suitable for the tests were 1800 and 2000rpm. For the same throttle position/ engine speed, th tractor speed would vary depending on the load, soil conditions, etc. In order to assess the actual tractor travel speed and wheel slippage by the tractor with the implement during operation at set engine speed, the time taken to traverse a distance of 20 metres marked out were observed with a stop watch.

For each field, the starting and ending time of each operation were recorded. Also, in between time taken for implement adjustment, turning at headlands, minor repairs and operators break were noted. For the rectangular plot, its length and breadth were measured, while for the irregular plot, its shape was sketched and critical dimensions were taken.

The actual width of cut was determined by measuring the distances between the adjacent furrows of tilled land, while the depth of tilling was determined by measuring the vertical distance between the bottom of furrow and the surface of the untilled land. All distance measurements were carried out using a measuring tape. For each field and operation, soil samples were taken for soil moisture content determination using oven method.

The fuel consumption was determined by starting an operation with a full fuel tank and topping of the tank after the completion of the operation. No fuel leakage was observed. The amount of the fuel used for the operation is equivalent to the quantity required to top the tank. The amount of fuel used for topping was measured with a graduated plastic jar.

3. RESULTS AND DISCUSSION

The selected field performance data of the tractor with the available tillage implements are given in Table 2. Some of the parameters were calculated using the following relationships:

(i) Wheel slippage is defined by Lljedahl *et al.* (1979) as:

$$S = 1 - \frac{V_a}{V_o} \qquad (1)$$

where V_o = theoretical no load wheel speed, km/h.
V_a = actual load wheel speed, km/h.

(ii) Field efficiency (E_f) is defined by Kepner *et al.* (1977):

$$E_f = \frac{100T_o}{T_e + T_h + T_a} \qquad (2)$$

where T_o = Theoretical operating time per hectare, min/ha.
T_e = Effective operating time = T_o x 100/K, min/ha.
K = percentage of implement width actually utilized, %
T_h = Time loss per hectare due to interruptions that are not proportional to area, min/ha.
T_a = Time loss per hectare due to interruptions that tend to be proportional to area, min/ha.

However, if K = 100%, the field efficiency becomes the percentage of total field time during which the machine was actually performing its function and the above equation (2) becomes:

$$E_f = \frac{\text{Actual operating time x 100\%}}{\text{Total Field Time}} \qquad (3)$$

(iii) Work rate or Effective Field Capacity (EFC) is defined as:

$$EFC = \frac{VWE_f}{10} \quad (4)$$

where V = rated speed of the tractor, km/h.

W = theoretical or rated implement width, m.

In this study, the actual tractor/ implement combination work rate was estimated using the simpler relationship:

$$EFC = \frac{\text{Actual Area of Field Covered}}{\text{Total Field Time}} \quad (5)$$

Test plot sizes varied between 0.13 and 2.06 ha with dimensions of between 30 and 250m in length. The soil conditions ranged between hard-dry to water logged with soil moisture content range of 5.2 and 22.4 percent. Under these varied soil conditions, tractor/ implement work rate during the tillage operations that is, ploughing, harrowing and ridging varied between 0.07 and 0.67ha/h with fuel consumption rate range of 2.0 to 20L/ha. For any of the tillage operations, the work-rate as well as fuel consumption varied depending on the soil condition and engine speed. Generally, less fuel consumption was observed for harrowing as compared to ploughing and ridging operations. The field efficiency ranged from 60 to 90 percent with overall mean of 74 percent. Kpner *et al* (1977) indicated that typical field efficiency values for tillage operations ranged between 75 and 90 percent for double axle tractors. Field efficiency generally is affected by time losses hich include the following:

(i) time for disengaging equipment from obstruction;
(ii) time for tuning at row ends,
(iii) time for minor repairs and adjustments; and
(iv) time for operators personal break.

Other highlights relating to specific tractor/ implement combination for a particular operation are summarized below:

3.1 Ploughing

For opening of new field and ridge splitting the performance of the tractor with disc plough with satisfactory with best performance output of 0.29 ha/h at 12.2 percent soil moisture content and wheel slippage of 9.4 percent. At lower soil moisture content, the penetration of the disc was poor. At higher moisture content, the penetration of the disc was poor. At higher moisture content there was excessive slippage which resulted in low work rate while at 22.4 percent moisture content the tyre occasionally sank.

Similarly, the lowest fuel consumption rate of 5.8 L/ha occurred at 11.4 percent soil moisture content, during which the tractor moved at its highest speed of 5.3km/h with wheel slippage of 11.3 percent. Fuel consumption was generally less for ridge-breaking than the opening of new flat field. The discs rolled over stumps without any damage.

3.2 Harrowing

The disc harrowing served mostly in secondary tillage operations, following ploughing for most fields. The best output rate was 0.67 ha/h at 9.9 percent soil moisture content, during which tractor speed and wheel slippage were 5.3km/h and 6.1 percent respectively. The lowest fuel consumption was 3 L/ha at 8.9 percent soil moisture content. Implement penetration range was 66 – 185mm with the deepest penetration without sinking at 9.4 percent soil moisture. The harrow did not require additional weight to get good penetration at optimum soil condition. Two or three harrowings were sufficient to prepare seedbed of acceptable quality.

3.3 Ridging

Ridger performance was generally satisfactory with higher output at soil moisture content range of 8 – 12 percent. At high soil moisture content, there was high slippage which resulted in lower output and higher fuel consumption rate. The highest output was 0.54 ha/h at moisture content of 8.3 percent and wheel slippage of 18.3 percent. Ridge height range was 198 – 20mm with the higher ridges at high wheel slippage and low tractor speed resulting in low output. At 2000rpm, ridge spacing and height were not uniform. In order to achieve acceptable ridges for planting, these were constructed at 1800rpm. Ridge spacing was fairly uniform but straight-line ridges depending mostly on the skill of the operator in addition to speed.

3.4 Transporting

The tractor/ trailer combination was used extensively for haulage of farm inputs, outputs and water for domestic use, all at varying load capacity. It was used on both surfaced highways and unsurfaced rural/ farm roads. Averages of the transport data are tabulated in Table 3. The performance varied with road surface and load capacity. While other implements were used during the rainy season for their specific operation, the trailer enjoyed all-season usage.

3.5 Breakdown and Operational Difficulties

As earlier indicated, the two season duration of the testing under different soil conditions; part of which were adverse, exposed the tractor/ implements to long reliability testing. The major breakdowns encountered during the testing include tyre bursting, slackening of steering arm bolt, excessive wearing of the clutch, broken rear axle shaft and front wheel spindle. The supplier responded promptly to the needed repairs and replacement, during the testing. There was no major breakdown of any of the implements.

The following are some of the operational difficulties:

1. The engine is hand starting and this proved very difficult for the average local farmer, that is, the user
2. The depth-wheel did not seem effective on controlling the depth of cut
3. In some difficult soil conditions of high moisture content, the tract sank and mostly there were hydraulic oil leakage. The latter is likely due to pressure build up in the hydraulic line.

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions could be made from the field evaluation of the Farmking tractor and the implements tested over the two farming seasons.

1. The soil condition varied from hard-dry to water logged with moisture content ranging from 5.2 to 22.5 percent. However, the optimum soil condition for the tillage operations seemed to be at a soil moisture content range of 9.0 to 14.0 percent in the locality.

2. The work rate of the tractor with the tillage implements ranged from 0.07 to 0.67 ha/h with fuel consumption rate of 2.0 to 20.2 L/ha depending on the soil condition, type of operation and speed of operation. In terms of this work rate, the tractor with the implements has potential for small holding farmers who constitute the bulk of agricultural producers in developing countries.

3. The optimum work rate was at tractor speed range of 4.4 to 5.5 km/h with wheel slippage range of 9.4 and 18.1 percent.

4. The overall mean field efficiency was 74 percent. This value appears slightly lower when compared with typical field efficiency values of 75 to 90 percent for double axle tractors.

5. Viewed from power rating of the tractor (16.8KW), its performance with the supplied implement was satisfactory especially in terms of quality of seedbed prepared from flat plots, which have been under continuous cultivation. In order to increase the versatility of the tractor so as to make it economical, its manufacturer/ supplier, should supply other potential implements such as planter, weeder, harvester, irrigation pump, etc.

6. The tractor is hand-starting, this is a limitation. Incorporating engine starting unit would make it easier for any user to start the engine without any difficulty. The hydraulic line should be redesigned to take higher pressure without leaking during all operations and under all soil conditions. Also, there is need to redesign both the rear axle shaft and the front wheel spindle to take greater load.

7. Although, the supplier reacted promptly to all needed maintenance and repair during the evaluation, the after sales service has always been a problem in tractor and implement dealership in Nigeria. It is hoped that the suppliers of the Farmking tractor will make conscious effort to ensure there is availability of spare parts for their product.

If the above recommendations are effected, the QM Farmking 200 tractors have potentials and could be recommended as prime mover for farm operations in tropical areas too. They have enough power to till and at higher work rates than most farmers are currently contending with manual or animal power systems. Since tillage operations constitute the most power demanding farming operation, the tractors would be able to perform satisfactorily in other operations such as planting, weeding and harvesting if appropriate implements are supplied.

Considering the economic level of most farmers in developing countries, the tractors might be too expensive for individual ownership except with government subsidy. Also, they could be jointly owned by a group of farmers.

ACKNOWLEDGEMENT

The author acknowledges the support of NAMCO Nigeria Limited, Kano, the supplier of the tractor with the implements, and the Institute for Agricultural Research (IAR), Samaru, Zaria; the testing institution.

NOTATIONS

S	Wheel Slippage, %
V_o	Theoretical/ no-load wheel speed, km/h
V_a	Actual/ load wheel speed, km/h
E_f	Field Efficiency, %
T_o	Theoretical operating time per hectare, min/ha
T_e	Effective operating time, min/ha
K	Percentage of implement width actually utilized, %
T_h	Time loss per hectare due to interruptions that are not proportional to area, min/ha
T_a	Time loss per hectare due to interruptions that tend to be proportional to area, min/ha
EFC	Effective field capacity, ha/h
V	Rated speed of tractor, km/h
W	Theoretical or rated implement width, m

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4.

Fig. 1 The QM Farmking 200 tractor and one of the implements.

Table 1: Monthly Rainfall Figure for 1986 - 1989 at Samaru, Zaria, Nigeria (mm). (*Source: Meteorological Service Unit, IAR, Zaria*).

Year	Month												Total	Mean
	J	F	M	A	M	J	J	A	S	O	N	D		
1986	0	0	0	6	59	82	294	322	206	0	0	0	69	80
1987	0	0	0	0	136	147	277	268	102	43	0	0	973	81
1988	0	4	0	35	94	133	182	403	192	115	0	0	1158	97
1989	0	0	0	15	113	124	155	170	118	53	0	0	748	62

Table 2: **Field Performance of Farmking 200 Tractor with Different Tillage Implements**

	1800 rpm		2000 rpm	
	Range	Mean	Range	Mean
(A) Ploughing (Disc Plough)				
2. Soil Moisture Content (db) (%)	5.2-22.4	12.0	9.3-16.7	12.0
3. Wheel Slip (%)	9.4-19.6	13.0	3.4-22.2	10.0
4. Tractor Speed (Km/h)	1.1-4.6	3.7	1.2-5.3	4.6
5. Working depth (mm)	138-264	199	140-250	189
6. Fuel Consumption Rate (L/ha)	8.3-20.2	13.5	5.8-16.6	12.0
7. Work Rate(ha/h)	0.07-0.29	0.19	0.12-0.25	0.20
8. Field Efficiency (%)	60-88	666	57-88	662
(B) Harrowing (Disc Harrow Tines)				
1. Soil Moisture Content (db) (%)	8.9-18.6	12.0	9.4-15.3	11.5
2. Wheel Slip (%)	8.2-16.9	14.9	6.1-10.3	7.9
3. Tractor Speed (Km/h)	3.3-5.7	4.3	5.0-5.8	5.3
4. Working depth (mm)	66-485	126	110-155	108
5. Fuel Consumption Rate (L/ha)	3.0-8.1	4.6	4.0-4.4	4.2
6. Work Rate(ha/h)	0.20-0.66	0.48	0.48-0.667	0.55
7. Field Efficiency (%)	82-90	84	83-90	85
(C) Ridging (Mouldboard Ridger, Disc Ridger)				
1. Soil Moisture Content (db) (%)	8.3-14.2	11.7		
2. Wheel Slip (%)	9.6-27.0	19.7		
3. Tractor Speed (Km/h)	2.0-4.6	3.2		
4. Working depth (mm)	198-260	230		
5. Fuel Consumption Rate (L/ha)	2.0-6.7	5.2		
6. Work Rate(ha/h)	0.23-0.54	0.34		
7. Field Efficiency (%)	68-85	71		

Table 3. Performance Data of Farmking 200 (16.8KW) Tractor when Coupled to a Trailer

Road Surface/ Load Capacity	Travel Speed (km/h)	Fuel Consumption Rate (L/km)
1. Trailer loaded on surfaced road (0.5 – 1.2 tons)	10.5	0.20
2. Trailer empty on surfaced road	17.4	0.14
3. Trailer loaded on unsurfaced road (0.5 – 1.2 tons)	13.4	00.32

Journal of Agricultural Engineering and Technology (1996), 4, 39-49

PREDICTING THE POWER REQUIREMENT AND THRESHING EFFICIENCY OF STATIONARY GRAIN THRESHER USING MATHEMATICAL MODELS

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ABSTRACT

The key to a successful model is to make approximations, which do not adversely affect the end results and in the final analysis the justification of any hypothesis rests on experimental reality. This paper presents a mathematical expression for predicting the power requirement and threshing efficiency of a grain threshing process. The characteristics and influence of various operating conditions and threshing parameters in a throw-in feed system of a stationary grain thresher were investigated. The model was verified and validated by fitting it into experimental data from stationary mechanical millet thresher. From the results it was found that the fitted model correlates well with the experimental data with an R-squared value of 0.99 at 0.001 level of significance.

The power requirements and threshing efficiency models were used to simulate the characteristics of a typical thresher and the results were found to predict well the general trend of performance.

1. INTRODUCTION

Threshing basically involves the detachment of grain kernels from the panicles. It is one of the most important post-harvest operations for cereal crops. Beating the pestle or stick and bullock treading of the harvested crops have been the traditional methods for threshing crops. The output of these methods is lowing leading to delays in handling a large volume of produce and consequent losses, while the cost of operation is high (Singh and Joshi, 1979).

The development of agriculture during the past century and the increased production per agricultural worker are due largely to the adoption of mechanical power for farm operations. In the recent times the adaptation of the internal combustion engine and electric motor for threshing operations in stationary powered grain threshers has contributed to progress in mechanization as they increase the magnitude of crop processed and reduce time spent to complete threshing operation when compared to human power and animal power.

The successful design and performance evaluation of a grain thresher depends upon the knowledge of the power requirement of threshing operation and other parameters such as threshing efficiency, grain loss and output capacity (Ndirika, 1997; Enaburekhan, 1994; Gregory, 1988; Vas and Harrison, 1969). But not much information is available on the power requirement for threshing operation. Huynh et al. (1982) in their study on threshing and separation process, presented a mathematical relation for thresher power demands. The equation developed was not verified and validated with an existing thresher. Also, they could not determine some of the constants in the equation. Threshing efficiency is an important parameter used in evaluating the performance of a grain thresher. It is often determined in terms of percentage of total grain received. However, there appears to be inadequate information available about the crop, machine and operational parameters pertaining to the performance of grain threshers. Moreover, the manufacturers of grain threshers are not completely unanimous in their views on cylinder concave configurations (Trollope, 1982). Therefore, in developing a stationary grain thresher, such parameters as cylinder peripheral speed, feed rate, cylinder concave configurations and moisture content have to be studied. Modeling of the threshing efficiency parameter in the threshing process would provide better understanding of the fundamental relationship of different machine and crop variables.

In previous studies, most of the models developed were for the grain combined system which has a different crop model from the stationary mechanical thresher (Trollope, 1982; Gregory, 1988 and Glassberg and McGechan, 1983). The limited work on mathematical models for stationary grain threshers have been reported by Vas and Harrison (1969), Huynh et al. (1982) and Enaburekhan (1994). The purpose of this study was to develop and verify mathematical models for predicting power requirement and threshing efficiency for the threshing operation in a stationary grain thresher.

2. THEORETICAL DEVELOPMENT

The principles of grain threshing were employed to formulate models to predict the power requirement and threshing efficiency of threshing operations. A beater or spike-tooth type of stationary grain thresher (Fig. 1) was considered, and a schematic description of the crop motion during threshing is presented in Fig. 2.

2.1 The Power Requirement Model

Using dimensional analysis and mechanistic theory, the total power requirement for threshing operation (P) was modeled as the sum of power required to overcome friction (P_f), the power required to detach grains from panicle (P_T) and the power required to turn the unloaded cylinder (P_r).

$$\text{i.e. } P = P_f + P_T + P_r \qquad (1)$$

Through dimensional analysis, the power required to overcome frictional force (P_f) can be expressed as (Ndirika, 1997):

$$P_f = K_f F_r V_b^2 \qquad (2)$$

Where,

K_f = a dimensional constant relating to the motion resistance of material
F_r = feed rate
V_b = Peripheral velocity of the cylinder

It was assumed that the pressure of the crop material on the concave surface is uniformly distributed over the entire length and width of the concave.

The power required to detach the grains from the panicle, P_T was determined by first determining the energy required to detach the grain from the panicle (E). Using dimensional analysis and assuming that the variables influencing E are crop velocity (V_c), crop bulk density (ρ_w), feed rate (F_r), concave clearance (c), concave length (L_c) and cylinder diameter (D), the energy required to detach grains from the panicle can be expressed as (Ndirika, 1997):

$$E = K_c \left[V_b \frac{F_r^3}{\rho_w} \right]^{1/2} \qquad (3)$$

where K_c = a constant (energy coefficient).

For a given concave length (L_c) and cylinder velocity (V_b), the dwell time (t_d) of the crop in the thresher can be expressed as (Ndirika, 1997):

$$t_d = \frac{L_c}{K_b} V_b \qquad (4)$$

where Kb = slippage factor for beater bars.

The power required to detach the grains from the panicle, P_T could be expressed as (Ndirika, 1997):

$$P_T = E/t_d \tag{5}$$

Substituting the value of E and t_d from equations ()3) and (4) respectively into equation (5), then

$$P_T = K_h \left[\frac{(V_b F_r)^3}{\rho_w L_c^2} \right]^{1/2} \tag{6}$$

where K_h = constant ($K_c \times K_b$).

The relationship between bulk density and moisture content of crop can be expressed as (Ndirika, 1997):

$$\rho_w = \frac{\rho_d}{1-\beta} \tag{7}$$

where,

ρ_w = bulk density of crop (wet basis)

ρ_d = bulk density of crop (dry basis)

β = moisture content of wet crop (decimal)

Substituting ρ_w from equation (7) into equation (6), then

$$P_T = K_h \left[(V_b F_r)^3 (1-\beta) \big/ \rho_d \, L_c^2 \right]^{1/2} \tag{8}$$

where the power required to run the cylinder without load (P_r) is expressed as (Ndirika, 1988):

$$P_r = NT \tag{9}$$

N = cylinder rotational speed without load, rpm

T = the torque required to run the cylinder without load, Nm

The torque required to run the cylinder without load can be expressed as (Ndirika, 1997):

$$T = M_c r \left(g + \frac{2V^2}{D} \right) \tag{10}$$

Where, M_c = mass of cylinder

R = radius of the driven pulley of the cylinder

D = effective diameter of the cylinder

V = velocity of the cylinder without load

g = acceleration due to gravitational force

Substituting the value of T from equation (10) into equation (9) and expressing the unit in Watt, then

$$P_r = 2\pi M_c r N \left(g + \frac{2V^2}{D} \right) \Big/ 60 \tag{11}$$

Substituting equations (2), (8) and (11) into equation (1), then the total power required for threshing operation (P) can be expressed as:

$$P = K_f F_r V_b^{\,2} + K_b\left[\frac{(F_r V_b)^3(1-\beta)}{\rho_d L_c^{\,2}}\right]^{1/2} + 2\pi M_c r V N\left(g + \frac{2V^2}{D}\right)\Big/ 60 \qquad (12)$$

2.2 The Threshing Efficiency Model

The probabilistic theory was introduced in deriving the threshing efficiency. Threshing process has been defined by an exponential function (Huynh et al., 1982 and Gregory, 1988). Therefore, the exponential probabilities density function is considered fit for describing and predicting the process performance. The process is considered as a probability of equal likely events which assumes that any grain has equal chance of being threshed at any time and has equal chance of reaching the concave surface at a given position. The exponential probability density function is defined as:

$$F(t) = \exp^{-t} \qquad (13)$$

Where t= time to occurrence of the random event (threshing of grain)
= 1/T (mean rate of threshing)
T = average time elapsed between the entry of crop into the thresher and threshing of grain.

Integrating equation (13) with respect to time, t at time intervals ($0 < t < t_d$) to obtain fraction of grain threshed within the interval, then

$$F(t),\ T_e = 1 - \exp^{-t} \qquad (14)$$

Equation (14) describes the threshing efficiency parameter (T_e) which depends on the rate of threshing and the dwell time (t_d) of the threshed grain in the threshing area. But dwell time can be expressed as (Ndirika, 1997):

$$t_d = \frac{L_c}{V_g} = \frac{1.5L_c}{V_b} \qquad (15)$$

where, L_c = concave length
V_b = peripheral velocity of the beaters
V_g = maximum velocity of grain after impact

and can be expressed as (Ndirika, 1997):

$$= K_T\left[\frac{\left(\rho_d D V_b^{\,2}\right)}{1-\beta}F_r\right] \qquad (16)$$

K_T = threshing factor (constant)
ρ_d = bulk density of crop (dry basis)
D = cylinder diameter
β = moisture content of crop (decimal)
F_r = feed rate

Substituting values from equation (15) and (16) respectively into equation (14), then threshing efficiency parameter is:

$$T_e = 1 - \exp\left[\frac{1.5K_T\rho_d D V_b^{\,2} L_c}{1-\beta}F_r\right] \qquad (17)$$

Equation (17) can be used to predict threshing efficiency.

2.3 Values of Constants

The constants in the developed models were determined by the method of least square analysis and by calculations using information from available literature and published data. The values of constants used are given in Table 1.

2.4 Verification and Validation of the Models

The models were verified in order to confirm their consistency with established experimental results from a thresher. The study was conducted on an existing millet thresher. Sensitivity curves which predict the characteristics of the models were plotted using data computed from simulation runs and the models were also compared with the experimental data.

3. MATERIALS AND METHODS

3.1 Simulation of the Power Requirement and Threshing Efficiency Models

The purpose of the simulation was to ascertain the characteristics of the models, which include feed rate (Fr), peripheral speed of cylinder (V_b), moisture content (β) and bulk density (ρ_d).

Digital computer simulation was employed in the study for the simulation. The effect of each characteristic was considered at 6 levels while the other effects were kept fixed in order to study the effect of each characteristic on the power requirement and threshing efficiency models. A computer flow chart for the models characteristic simulation programme was used to make calculations on the models. The specifications of the cylinder-concave unit and the operating conditions of the thresher used are contained in Tables 2 and 3 respectively. Coefficients of variation (Cv) of the effects of each characteristic on the models were determined.

3.2 Predicted Power Requirement and Threshing Efficiency Model Compared with Measured Experimental Data

The method developed by Gregory and Fedler (1986) for calculating the coefficient of determination, R^2 statistically for nonlinear as well as linear functions and with one or more independent variables is the function used in the work:

$$R^2 = 1 - \frac{V_o}{V_t} \qquad (18)$$

where R^2 = coefficient of determination
V_o = estimated variance not explained by the model
V_t = estimated variance about mean

Since the R^2 valued from the equation (8) must have a level of significance before the model is considered verified, the statistical significance test was employed to ascertain how adequately the sample data set used for developing the model represents the whole population. The significance level for a given R2 can be obtained by computing 't' with the following equation (Snedecor and Cockron, 1980):

$$t = \frac{R(D_f)^{1/2}}{(1 - R^2)^{1/2}} \qquad (19)$$

where t = student's 't' value
R = square root of coefficient of determination
D_f = degrees of freedom (number of data point minus number of constant defined in the model).

Line of good fit (1:1 line) was presented graphically and also used to compare the predicted and the measured results.

3.3 Instrumentation and Measurement

The data generated from the stationary millet thresher used in the verification of the power requirement and threshing efficiency models were measured or evaluated by the following methods:

Moisture Content Determination: Moisture content of crop was determined by oven dry method at a temperature of 130°C of 18 hours (ASAE, 1972).

Weight Measurement: A mettler balance with 0.01g calibration was used for weighings.

Power Measurement: A wattmeter with 0-4, 800 watt calibration rating was used for the power measurement.

Speed Measurement: A revolution counter (tachometer) was used for speed measurement.

4. RESULTS AND DISCUSSION

4.1 Influence of Variables

The characteristics of the developed model and the influence of variables (feed rate, cylinder speed, moisture content, bulk density and mass of cylinder) on the predicted power requirement and threshing efficiency models are presented.

4.1.1 Effect of Feed Rate

The extent of variation in the power requirement as affected by feed rate is 0.0013% which is less than the value obtained with the threshing efficiency (2.56%). The result reveals that the effect of feed rate for both models has no significant effect at ($P \leq 0.05$) level of significance (Table 4).

4.1.2 Effect of Cylinder Speed

From Table 4, the extent of variation in the power requirement as effected by cylinder speed is 33.39% which is higher than the value obtained with the threshing efficiency (1.12%). The result also revealed that the effect of cylinder speed on the power requirement is significant at 5% level of significance while the effect was not significant in the threshing efficiency model.

4.1.3 Effect of Moisture Content

Even though the extent of variation in the threshing efficiency as affected by moisture content is higher (0.10%) than with the power requirement model (0.0011%), the effect of moisture content for both models has no significant effect at ($P \leq 0.05$) as indicated in Table 4.

4.1.4 Effect of Bulk Density

The extent of variation in the power requirement as affected by bulk density is 0.0012% which is less than the value obtained with the threshing efficiency (1.02%). The result reveals that the effect of bulk density for both models has no significant effect at ($P \leq 0.05$) (Table 4).

4.1.5 Effect of Mass of Cylinder

From Table 4, the extent of variation in the power requirement as affected by the mass of cylinder is 7%. The parameter has a significant effect on the model at 5% level of significance.

4.2 Model Validation

From Table 5, it was established that R-square values of 0.9954 and 0.9880 respectively were obtained for the power requirement and threshing efficiency models, also the calculated 't' values obtained for both models were higher than the table 't' values at 0.001 levels of significance. It was revealed in Figures 3 and 4 that the fitted power requirement and threshing efficiency models gave a good correlation and thus fit well with the measured power and measured efficiency from the millet thresher.

5. CONCLUSION

The following conclusions can be drawn from the results of this study:

1. The power requirement for the threshing operation in a stationary grain thresher can be described with a mathematical model which include parameters such as feed rate, cylinder speed, moisture content, bulk density, concave length, cylinder diameter, mass of cylinder and radius of driven pulley, while the threshing efficiency model includes parameters such as feed rate, cylinder speed, concave length, moisture content, bulk density and cylinder diameter.

2. However, the most significant parameters influencing the predicted power requirement are the cylinder speed and the mass of cylinder.

3. The predicted power requirement and the threshing efficiency by the models are in close agreement with the experimental result from an existing millet thresher.

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Table 1. Values of Constants

S/N	Constant	Value	Source
1	K_h	0.36	Huynh et al. (1982) & Wagami (1979)
2	K_f	0.06	Henderson and Perry (1976) & Huynh et al. (1982)
3	K_e	0.91	Wagami (1979)
4	K_b	0.4	Huynh et al. (1982)
5	π	3.14	
6	K_T	0.0021	Wagami (1979)

Table 2. Cylinder and Concave Data for Millet Threshers

S/N	Parameter	Dimension
1.	Effective cylinder diameter, D	0.350m
2.	Concave length, L_c	0.360m

Table 3. Crop and Operating Conditions for Millet Thresher

S/N	Parameter	Value/ Level					
		1	2	3	4	5	6
1.	Feed rate, F_r (kg/s)	0.02	0.03	0.04	0.05	0.06	0.07
2.	Cylinder speed with load, V_b (m/s)	3.40	3.72	3.85	4.14	4.65	5.0
3.	Cylinder speed without load, V (m/s)	3.93	4.0	4.50	4.80	5.0	5.5
4.	Cylinder rpm without load (N)	400	500	600	700	800	900
5.	Radius of cylinder pulley (r), m	0.094	0.076	0.072	0.065	0.060	0.058
6.	Moisture content, β (decimal)	0.09	0.10	0.11	0.12	0.13	0.14
7.	Bulk density, ρ_d (kg/m^3)	102.0	98.60	90.20	82.83	75.80	62.12
8.	Mass of cylinder M_c (kg)	2.5	2.6	2.7	2.8	2.9	3.0
9.	Crop variety	Ex-Borno					

Table 4. The Extent of Variation in Power Requirement and Threshing Efficiency as Affected by Variables at ($P \leq 0.05$) Level of Significance

Models	Coefficient of Variation, C_v (%)				
	Feed rate (F_r)	Cylinder speed (V_b)	Moisture Content (β)	Bulk Density (ι_d)	Mass of Cylinder (M_g)
Power Requirement (P)	0.0013 n.s.	33.39*	0.0011 n.s.	0.0012 n.s.	7.0*
Threshing Efficiency (T_e)	2.56 n.s.	1.12 n.s.	0.10 n.s.	1.02 n.s.	-

n.s. – not significant
* Significant

Table 5. Calculation R2 and 't' Values of the Compared Predicted Power Requirement and Threshing Efficiency with Measured Data from Millet Thresher at $P < 0.001$ Level of Significance

Models	Validation Parameters		
	R^2 Values	Calculated 't' Values	Table 't' Values
Power Requirement (P)	0.9954	32.90	6.869
Threshing Efficiency (T_e)	0.9880	20.29	6.689

Fig. 1 & 2

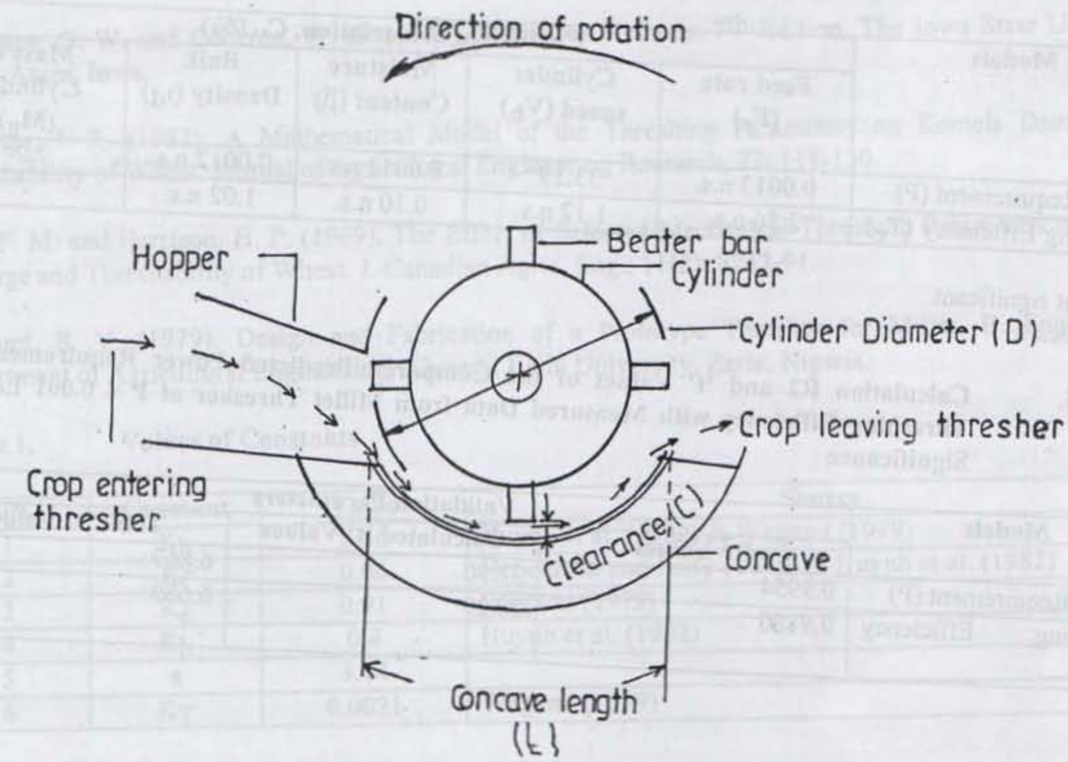

Fig. 1 : Cylinder - Concave arrangement of the spike tooth thresher

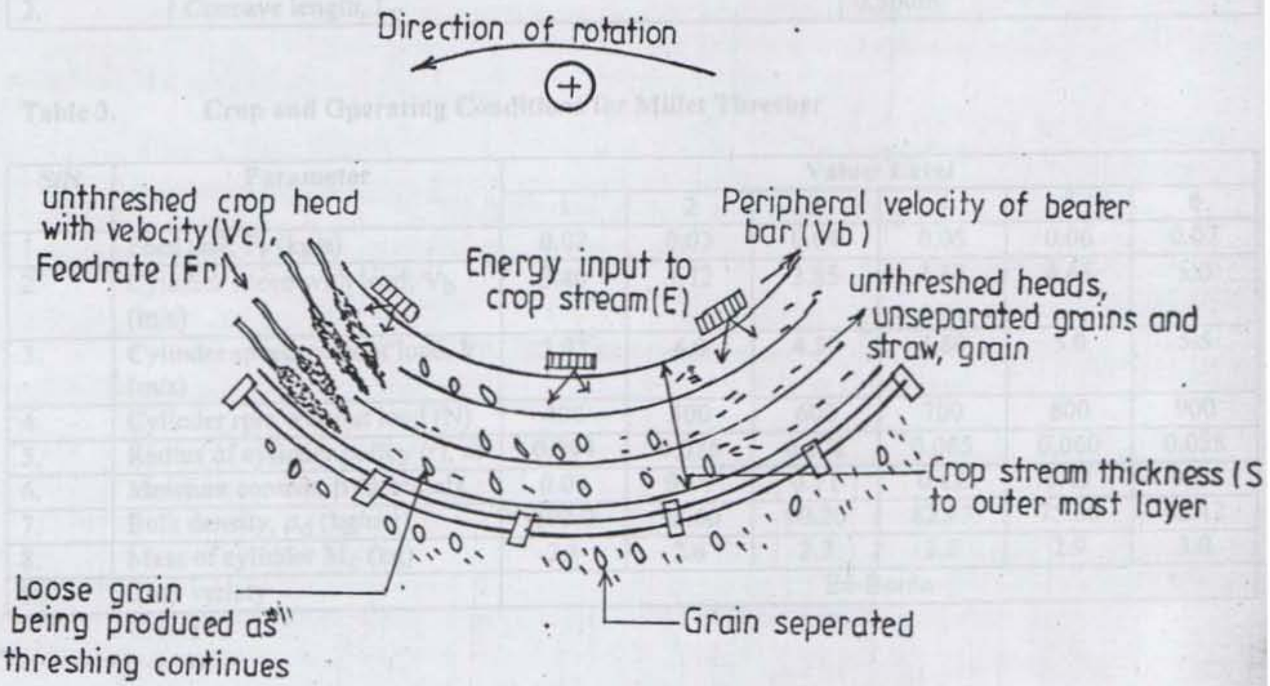

Fig. 2 : Schematic description of crop motion during threshing & separation processes of the model

Fig. 3

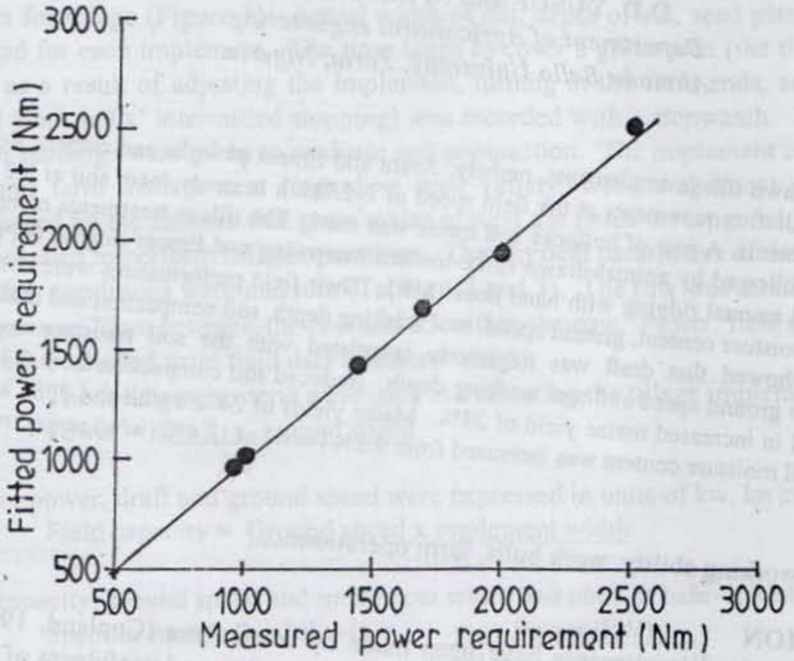

Fig.3: Measured vs fitted power requirement for a millet thresher.

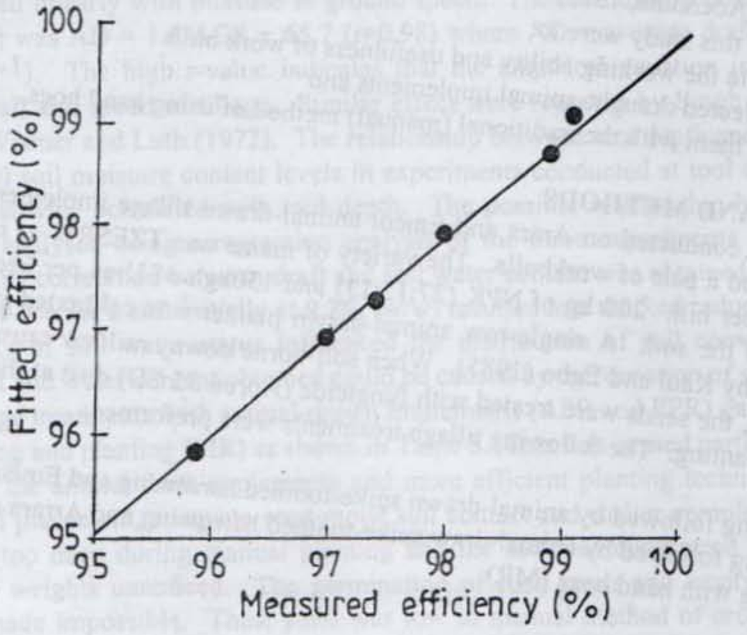

Fig. 4: Measured vs fitted efficiency for a millet thresher

Journal of Agricultural Engineering and Technology (1996), 4, 50-57

INVESTIGATIONS ON THE WORKING ABILITY AND USEFULNESS OF WORK BULLS FOR FARM OPERATIONS

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ABSTRACT

Animal-drawn tillage implements, namely; Arara and Emcot ploughs and ridgers were tested to determine their draft requirements at the field speed of 2-2.7kh/h in sandy loam soil at 9.2 - 12.4% (w/w) moisture contents. A pair of bullocks and maize was used. The tillage treatments comprised of: emcot ploughing followed by animal-drawn spike-toothed harrowing and Emcot ridging (EPR): Arara ridging (APR) and manual ridging with hand hoes (MR). Their field performances were compared in relation to draft, moisture content, ground speed, tool working depth, soil compaction and maize yield.

Results showed that draft was negatively correlated with the soil moisture content and positively with the ground speed and tool working depth. Reduced soil compaction from 0.37 Mpa to 0.32 Mpa resulted in increased maize yield of 24%. Maize yields of 2472 kg/ha and 3086 kg/ha were obtained when soil moisture content was increased from 9.2% (w/w) to 12.4% (w/w) respectively.

KEYWORDS

Investigations, working ability, work bulls, farm operations.

1. INTRODUCTION

Design of draft-animal implements have been made by researchers (Copland, 1970; keener et al., 1978 and Adam and Adam, 1993). Investigations on the working ability and usefulness of these implements for farm work are much neglected and not common in the literature. Researchers (Gill and Vander Berg, 1967; Yond, 1968 and Fruitage et al., 1970), have indicated that lack of understanding of pertinent soil-machine parameters is the cause of most prediction inaccuracies. For effective mechanization of a predominantly peasant agriculture, there is need not only for the design of new equipment but also for the testing of available ones (Adenoma, 1988).

The objectives of this study were to:

(i) Investigate the working ability and usefulness of work bulls Using selected draught-animal implements and

(ii) compare them with the traditional (manual) method of using hand hoes.

2. MATERIALS AND METHODS

Field tests were conducted on Arara and Emcot animal-drawn tillage implements using maize (zea *Mays L.) as test crop and a pair of workbulls. The variety of maize was TZESRW at seed rate of 24kg per* hectare and at 2 seeds per hill. 200 kg of NPK (27:13:13) and 150kgh of Urea per hectare were applied to maintain the fertility of the soil. A single-row animal-drawn planter was calibrated in the field using the procedure as described by Kaul and Egbo (1985). When soil-borne downy mildew caused by peronosporales in maize was suspected, the seeds were treated with fungicide (Apron 35 SD) dust at the rate of 500g dust to 100kg of seed before planting. The following tillage treatments were preformed:

1. Emcot ploughing followed by animal-drawn spike-toothed harrowing and Emcot ridging (EPR);
2. Arara ploughing followed by animal-draw spike-toothed harrowing and Arrara ridging (APR);
3. Manual ridging with hand hoes (MR).

Animal-drawn single-row planter was used to plant maize on plots treated with animal-drawn implements while manual planting was carried out on plots that were ridged manually. The on-farm tests were undertaken in June, 1995, in a field with sandy loam soil texture at Samaru ($11^{o}11^{1}$N, $07^{o}38^{1}$E and 685m above sea level). The soil moisture content was determined in the laboratory. Dilton dynamometer (sensitivity = 96%) was fitted to each implement and attached to the draught animals to assess their draft requirements for tillage (Figure 1). Actual width of cut, depth of cut, seed placement and distance traveled were recorded for each implement. The time taken to cover a given area (the time of operation included all such losses as a result of adjusting the implement, turning at the farm ends, adding seeds and fertilize. to hoppers and work bulls' intermitted stopping) was recorded with a stopwatch. In each of the planting runs, penetrometer readings were taken to evaluate soil compaction. The implement combination, number of farm operations and farm management (regarding seed variety, weed and insect control) were based on the practice followed by the farmers that grow maize around the fields investigated. The workbulls had training and have been used to perform tillage operations. The physical parameters of the ploughmen and the animals and the weather conditions were measure (Tables 1,2 and 3). The row was arranged across the slope and the crop spacings were 75cm between-the-row and 25 within-the-row. Power, field capacity, specific energy and crop yield were evaluated from field data (Tables 4 and 5).

The following criteria were used in evaluating the tillage implements:

1 $$\text{Power} = \frac{\text{Draft x ground speed}}{3.6} \quad (1)$$

where power, draft and ground speed were expressed in units of kw, kn and kmhr-1 respectively.

2. $$\text{Field capacity} = \frac{\text{Ground speed x implement width}}{10.0} \quad (2)$$

where field capacity, ground speed and implement width had units of hahr-1, kmhr-1 and m respectively.

3. $$\text{Specific energy (kw.hrha-1)} = \frac{\text{Power (kW)}}{\text{Field capacity (hahr-1)}} \quad (3)$$

The accrued data were analysed using statistical techniques, including means, standard deviation, coefficient of variance, percentages and regression analysis.

RESULTS AND DISCUSSIONS

The relationship between the speed and draft at 10-20cm depths of tillage are shown in Table 4. The draft increased linearly with increase in ground speed. The relationship obtained for the average speed and average draft was AD = 1.6 AGS + 65.7 (r=0.98) where AD = average draft (kg); AGS = average ground speed (kmhr^{-1}). The high r-value indicates that the empirical equation is reasonable for describing the combined draft and speed of tillage. Similar effect were reported by Singh et al (1991), Luth and Wismer (1971) and Wismer and Luth (1972). The relationship between tool depth and draft obtained at 9.2, 10.1 and 12.4% (w/w) soil moisture content levels in experiments conducted at tool depths of 10-12cm showed that draft was positively correlated with tool depth. The possible relationship between draft and soil moisture content was analysed using a regression analysis of the three experiments in combination (Figure 2). A linear, negative correlation between draft and soil water content was obtained. Increase in soil water content by a little as 0.9% for a soil initially at 9.2% (w/w) resulted in a marked reduction of implement draft. Since the variability of soil water status influenced the distribution of soil compaction (Table 5), the relation between draft and water content obtained could be caused by the variation of soil compaction.

Tillage treatments with animal-drawn implements (APR and EPR) gave higher maize yields than the manual ridging and planting (MR) as shown in Table 5. This was caused partly by low penetration resistance recorded for the animal-draft implements and more efficient planting technique (in respect of appropriate depth of seed placement, adequate seed-moist soil contact and earlier completion of planting). Some seeds were buried too deep during manual planting and the soil was compacted too much by the farmers who exerted their weights unnoticed. The germination of such seeds and emergence of seedlings were either delayed or made impossible. Thus, yield was low in manual method of crop production. It indicates that excessive soil strength and soil resistance to penetration are detrimental to crop yield. The minimum and maximum increase in maize yield of 12% and 32% respectively over the manual ridging and planting under the same management practices showed the superiority of the animal-drawn implements and appeared to be better alternative because the soil environment remained suitable for high crop yield.

3. CONCLUSIONS

The following conclusions can be drawn from the on-farm study;

1. Draft was negatively correlated with the soil moisture content and positively with the ground speed and depth of tillage.
2. Increased tillage depth increased the power requirement but decreased the specific energy input.
3. Excessive soil strength and soil resistance to penetration are detrimental to crop yield.

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Table 1. Personal Data on Test Farmers

Parameters	Test Farmers		
	1	2	3
Farmer's personal data			
Sex	Male	Male	Male
Age	40	43	38
Height, m	1.6	1.5	1.7
Body weight, kg	65	60	63
Body surface area, m^2	1.7	1.6	1.7
Occupation	Farming	Farming	Farming
Health condition (subjective)	Good	Good	Good

Table 2. Climatic Conditions during the Field Trial at Samaru, Nigeria

Climatic Conditions	Range	Mean	CV (%)
Air temperature, ^{o}C	24.2-35.0	29.2	12.3
Relative humidity, %	62.0-82.8	71.0	9.9
Atmospheric pressure, mmHg	754.0-758.0	756.0	0.3
Soil moisture, % w/w	9.2-12.4	10.6	12.7

Table 3. Physical Measures of the Work Bulls

Physical Measures of the Animal	
Number and type of animal	One pair of N'Dama bullocks
Age, yrs	11
Body weight, kg	666
Height of front knee, m	0.79
Height of rear knee, m	0.88
Overall body height, m	1.6
Overall body width, m	2.1
Effective daily working period, hrs	4.1

Table 4. Performance Characteristics of Arara and Emcot Equipment during 1995 Cropping Season at Samaru, Nigeria

Equipment for field operation	Moisture content (% w/w)	Depth of cut (cm)	Draft (kg)	Unit draft (kg cm^{-2})	Ground Speed (km/h)	Tractive horsepower (hp)	Draft Power (KW)	Field capacity (ha/h)	Specific energy input (KW-h/ha)	Mean clod diameter (mm)
Arara Plough (AP)	9.2	10.4	69.19	0.59	2.51	0.63	0.458	0.028	16.357	28.1
Emcot Plough (EP)		11.6	70.10	0.43	2.70	0.70	0.515	0.037	13.919	29.6
Arara Ridger (AR)		17.8	71.83	0.27	2.14	0.57	0.418	0.032	13.063	27.5
Emcot Ridger (ER)		18.2	75.75	0.26	2.22	0.62	0.457	0.035	13.057	26.4
$\bar{X}$		14.5	71.72	0.39	2.39	0.63	0.462	0.033	14.099	27.9
S.D.		3.5	2.51	0.13	0.23	0.05	0.035	0.003	1.350	1.2
C.V. (%)		24.1	3.50	33.33	9.62	7.94	7.576	9.091	9.575	4.3
AP	10.1	11.2	62.26	0.51	2.32	0.54	0.393	0.026	15.115	223.8
EP		13.8	70.64	0.37	2.58	0.68	0.495	0.036	13.750	27.5
AR		18.5	68.32	0.25	2.10	0.53	0.505	0.032	15.781	24.1
ER		19.1	74.61	0.26	2.13	0.58	0.432	0.032	12.706	25.2
$\bar{X}$		15.7	68.96	0.35	2.28	0.58	0.456	0.032	14.338	25.2
S.D.		3.3	4.47	0.10	0.19	0.06	0.046	0.004	1.193	1.5
C.V. (%)		21.0	6.48	28.57	8.33	10.34	10.088	12.500	8.321	5.9
AP	12.4	11.9	58.34	0.45	2.29	0.50	0.363	0.025	14.520	24.4
EP		15.2	70.10	0.33	2.41	0.63	0.459	0.034	13.500	23.8
AR		18.8	65.41	0.24	2.00	0.49	0.356	0.030	11.867	24.0
ER		20.0	73.01	0.25	2.10	0.57	0.417	0.032	12.265	25.1
$\bar{X}$		16.5	66.72	0.32	2.20	0.55	0.399	0.030	13.038	24.3
S.D.		3.2	5.54	0.08	0.16	0.06	0.042	0.003	1.046	0.5
C.V. (%)		19.4	8.30	25.00	7.27	10.91	10.526	10.000	8.023	2.1

Remarks: Ridge height =28cm; vegetative cover – nil; previous crop – cowpea; field condition – previously ploughed.

Table 5. **Effect of Soil Compaction on Maize Yield at Samaru During 1995 Cropping Season**

Tillage Treatment	Replication	Moisture content (% w/w)	Mean Penetration Resistance* (Mpa)		Yield ** (kg/ha)	Increase in yield over control (%)
			Unplanted Land	Planted Land		
APR	RI	9.2	0.52	0.32	2472	24.4
EPR			0.52	0.35	2261	13.7
MR			0.52	0.37	1988	-
					$\bar{X}$ =2240.3	
					C.V. = 8.8	
APR	RII	10.1	0.48	0.27	2921	31.9
EPR			0.48	0.29	2630	18.8
MR			0.48	0.26	2214	-
					$\bar{X}$ =2588.3	
					C.V. = 11.3	
APR	RIII	12.4	0.41	0.24	3086	23.3
EPR			0.41	0.24	2811	12.4
MR			0.41	0.20	2502	-
					$\bar{X}$ =2240.3	
					C.V. = 11.3	

* Each value is a mean of five observations, $\bar{X}$ = mean and C. V. = coefficient of variance.

** Yield was determined by hand harvesting of four 210m^3 plots at 14 percent moisture

Fig. 1

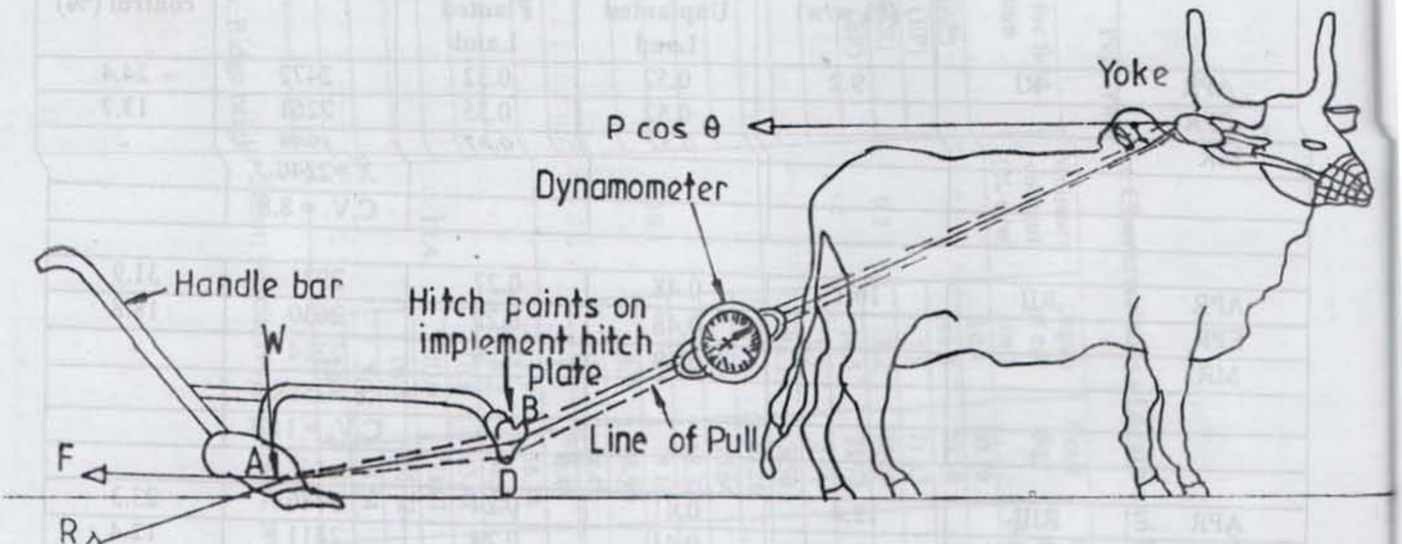

Fig. 1: Vertical adjustment of walking moldboard plough bottom: W, implement gravitational force: F, useful soil force: R, resultant force.

Fig. 2

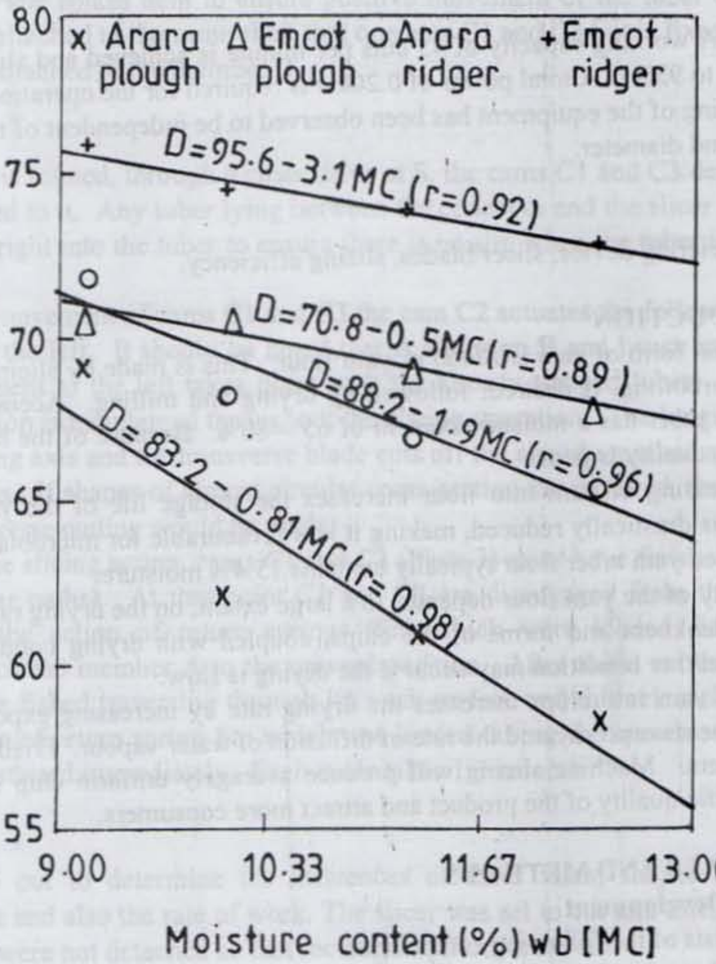

Fig.2: Effect of Moisture on Draft

Journal of Agricultural Engineering and Technology (1996), 4,58-64

A MACHINE FOR SLICING YAM TUBERS

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ABSTRACT

A Machine for slicing yam tubers was designed and constructed. With the exception of branched tubers, this machine can handle any other shape and size. Two shapes of yam chips are obtainable, namely, rectangular and round shapes, depending on the fixed slicer blades. Thickness of slices can be varied according to user's requirement, ranging from 2mm.

A working capacity of 45 cuts per minute is achieved and slicing efficiency ranged from 82 to 93%. A total power of 0.20kw is required for the operation of the machine. The functioning of the equipment has been observed to be independent of tuber moisture content, weight and diameter.

KEYWORDS

Tuber metering device, slicer blades, slicing efficiency.

1. INTRODUCTION

A common form of yam is *Elubo* or yam flour. This is made by slicing peeled tubers to a thickness of about 1cm; parboiling, if desired; followed by drying and milling. According to Ngoddy and Onuoha (1983) fresh yam tuber has a moisture content of 65 – 80%. Because of the high moisture content of fresh tuber, the keeping quality is poor.

The processing of yam into flour increases the storage life of the yam (Osagie, 1992) since the moisture content is drastically reduced, making it less favaourable for microbial activities. Adamson (1985) stated that sun-dried yam tuber flour typically contains 15.4% moisture.

The quality of the yam flour depends, to a large extent, on the drying rate of the chips which, in turn, depends on the thickness and forms of the chips, coupled with drying conditions. Losses in quality of nutrients due to weather condition may occur if the drying is slow.

Slicing of yam into chips increases the drying rate by increasing exposed surface area, number of exposed voids solar absorptivity and the rate of diffusion of water vapour. Fried yam chips are also served in various food centers. Machine slicing will produce averagely uniform chip shapes and sizes. This will increase the aesthetic quality of the product and attract more consumers.

2. MATERIALS AND METHODS

2.1 Machine Development

The Machine consists of the following components:

(i) Tuber metering device which performs the following functions:

(a) ensuring that the tuber is held down and kept from rocking during the metering and slicing processes

(b) ensuring that the tuber is metered into the slicer blades for cutting a pre-set thickness of chips.

(ii) A bed on which the tuber rests while it is being handled
(iii) Two sets of blades for making both longitudinal and transverse cuts.
(iv) Transmissions that properly time the metering of material with slicing action and the motion of the longitudinal slicer blades with that of transverse blade.

The tuber-metering device, HD, is mounted over the slicer bed, B, see Plate 1, while the slicer blades are positioned at the end of the bed. The arrangement of the system is shown in Plate 2. The metering device, shown more clearly in Plate 3, is a very compact unit. Three sets of cam-and –follower arrangement have been employed. The cams are labeled C1, C2, and C3. C1 and C3 work together. The followers, which are of the roller type, are not seen from the figure. The followers, which are of the roller type, are not seen from the figure. The followers for C1 and C3 are attached to a shaft which is, in turn attached to the member B. The part D is fixed to a frame while B is free to slide left and right, on it (D). Concaves, P, known as pressure concaves, are welded to short pieces of metal rods which are free to slide, up and down, inside A. The concaves make direct contact with the tuber and each surface hold a spike of about 3mm diameter and 10mm long. The spikes help to ensure positive movement of the tuber during the metering action. The cam C2 is also attached to the same shaft that operates C1 and C3 but is fixed 10^{0} behind C1 and C3. The follower for C2 is attached to the member B.

2.2 Operation

When the camshaft is rotated, through a chain drive at S, the cams C1 and C3 depress the member A through the follower attached to it. Any tuber lying between the concaves and the slicer bed is trapped. The spikes on the concaves dig right into the tuber to ensure there is no slip when the tuber is slid forward to the slicer blades area.

After about 10^{0} of movement of cams C1 and C3 the cam C2 actuates the follower attached to B and this moves that member to the left. It should be noted that A slides on B and hence must move to the left along with B. This movement to the left takes place with the already trapped tuber. This constitutes the metering action. This position is maintained throughout the slicing operation. The longitudinal slicer blades first make cuts along the long axis and the transverse blade cuts off the already marked area to get yam chips of almost rectangular shapes. If shapes of almost circular cross-section are required, the longitudinal blades are detached and only transverse cutting would be made.

At about 5^{0} after the slicing action, cams C1 and C3 (Plate 3) must have finished traversing through their work surfaces (circular paths). At this point C1 and C3 are disengaged from their followers. This happens sharply through the action of return springs (Sn) which were loaded during the downward movement. This brings back the member A to the upward position. After about another 5^{0} of rotation the cam C2 (Plate 3) must have fished traversing through its work surface and this releases B back to the right hand side through the action of return spring Sm which was loaded during the movement to the left. At the end of the cycle, another is started immediately. Each cycle takes 1.3 seconds.

2.3 Test Procedure

Tests were carried out to determine the influences of tuber sizes, shapes and weights on the performance of the machine and also the rate of work. The slicer was set to cut to a thickness of 10mm. The longitudinal-cutting blades were not detached so that rectangular slices were cut.

Ten peeled tubers of white yam were fed in simultaneously. The tubers, which were bought randomly from a local market, were peeled mechanically, using a system developed by the author, and still under further research. When the slicer blades were about to finish cutting through each tuber, there was an unsliced length (an off-cut), which fell off the unit into the yam chips container. An off-cut resulted when tuber length was so small that it lost stability necessary to keep it in place for onward metering to the slicer blades. This loss of stability was caused by the vibration of the system which resulted from the movement of the return springs.

The slicing efficiency of the machine was therefore calculated as follows:

$$\text{Slicing efficiency (\%)} = \frac{Li - Lo}{Li} \times 100$$

Where Li = tuber initial length, mm
Lo = length of off-cut, mm

Plates 4 and 5 show the forms of yam chips, which the machine produces. The detachment of the longitudinal-cutting blades (to get round slices) does not alter the metering of tubers to the blades. This is why the experiment did not consider round chips also in data collection.

3. RESULTS AND DISCUSSION

The test data are shown below.

Result of the Performance Test of the Machine

No	Tuber Length (mm)	Sliced Length (mm)	Unsliced Length (mm)	Slicing Efficiency (%)	Slice Thickness (mm)	Slicing Time (s)	Tuber Ave. Dia. (mm)	Tuber wt (kg)
1	388	357	31	92.01	10	62	76.5	1.92
2	380	258	42	86.00	10	50	98.1	1.99
3	370	344	26	92.97	10	59	86.6	1.91
4	335	275	60	82.09	10	50	80.4	1.25
5	332	302	30	90.96	10	58	101.9	1.13
6	325	290	35	89.223	10	57	72.3	1.35
7	280	243	37	86.79	10	42	71.9	1.23
8	310	269	41	86.77	10	52	81.5	1.90
9	415	390	25	93.98	10	66	66.3	1.02
10	310	282	28	90.96	10	553	72.4	1.38

The slicing efficiency correlated with tuber diameters. This was to ascertain whether tuber sizes affected the handling capacity of the equipment. A correlation coefficient of –0.18 was obtained, indicating that the larger the tuber diameter the more the off-cuts resulted. However, looking at the closeness between the variables in question, only 3.24% (coefficient of determination) of the variation in tuber sizes caused a corresponding variation in the amount of off-cuts that resulted. This figure is very negligible, and is therefore ignored.

It is possible that the shapes of tubers introduced some difficulty in sliding the tubers to the slicer blades, by the metering device. A correlation analysis that was run between tuber lengths and slicing time gave a coefficient of 0.958. It means that more time was spent in slicing longer tubers and this happened irrespective of tuber shapes. This claim of non-involvement of tuber shapes is further proved by the fact that the thickness of each slice measured 10mm as already set on the machine. The uniform slice thickness also proves that the performance of the slice is independent of tuber weight..

A maximum off-cut length of 60mm and a minimum value of 25mm were obtained, corresponding to an efficiency range of 82.09 – 93.98%.

The rate of work would be the length of tuber sliced per unit time. This parameter cannot be clearly stated except the thickness of cut is stated also. As would be expected, for the same tuber length it takes shorter time to slice into thicker pieces and vice versa for thinner pieces. Because of this difficutlty, the rate of work would be looked at from the angle of cuts per minute. The slicer blades work at 45rpm and each revolution makes a cut.

4. CONCLUSION

A yam tuber-slicing device was designed, fabricated and tested. Two forms of yam slices can be produced by this equipment, namely, round and rectangular slices. The thickness of cut can be varied from 2mm to 20mm, depending on the user's requirements.

From tests, slicing efficiency ranged from 82 to 93% and the rate of work is 45 cuts per minute. Tuber sizes, shapes and diameters do not affect the working of the machine.

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Plates 1 & 2

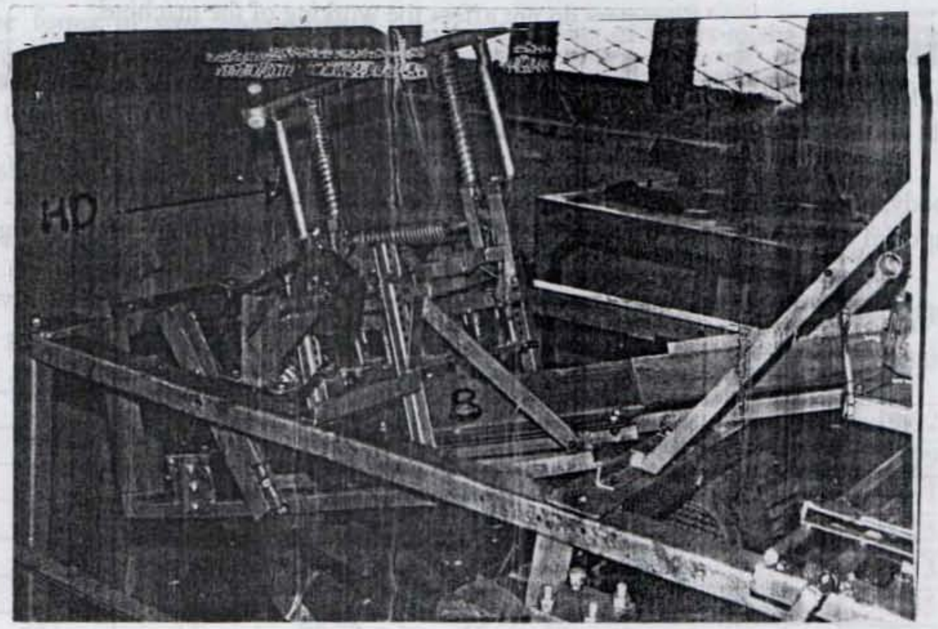


Plate 1: The slicer unit.

HD - Metering device, B - Slicer bed.

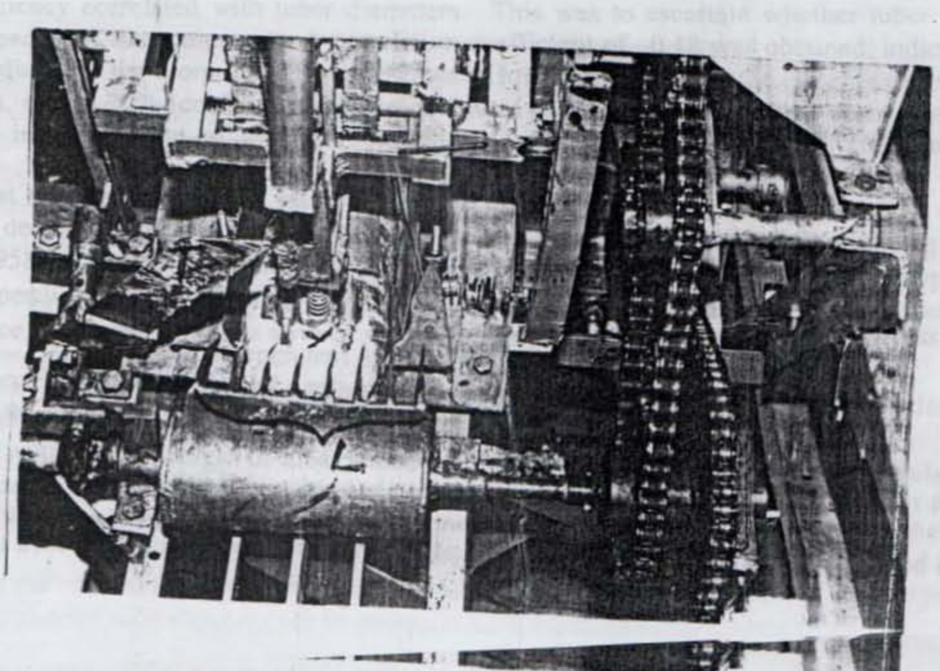


Plate 2: Slicer blades arrangement.

T - Transverse-cutting blade,
L - Longitudinal-cutting blades,
Y - Yam tuber.

Plate 3

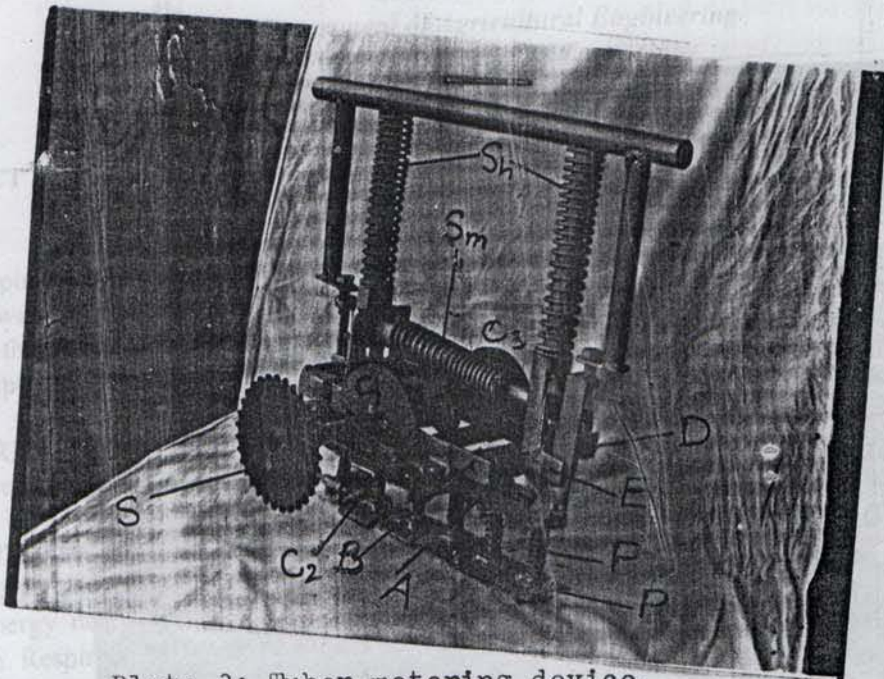
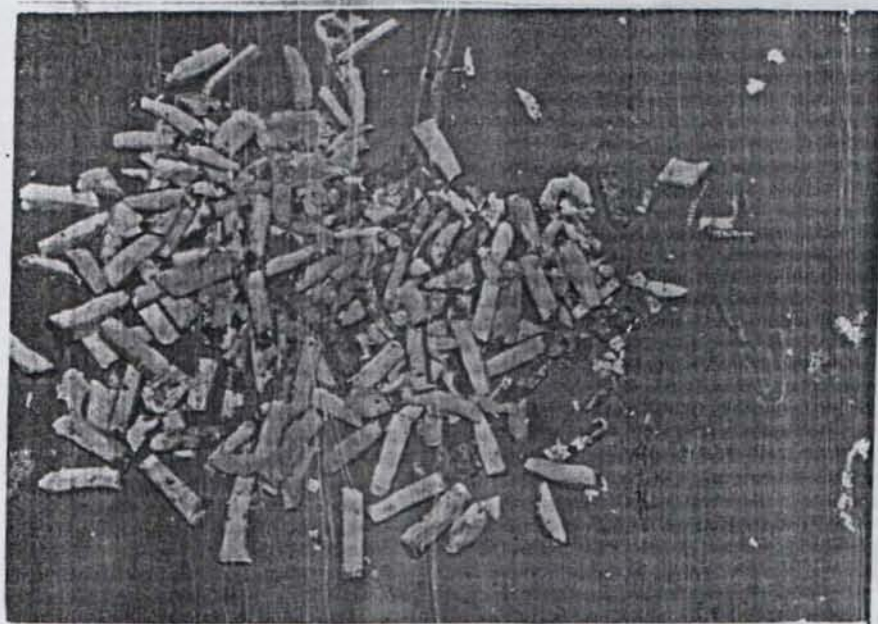


Plate 3: Tuber metering device.

A, B, - members A & B; C_1, C_2, C_3, - cams; D - member fixed to the frame; E - extension on B; F - spring; P - concave; S - sprocket; S_h - vertical return spring; S_m - horizontal return spring.

F



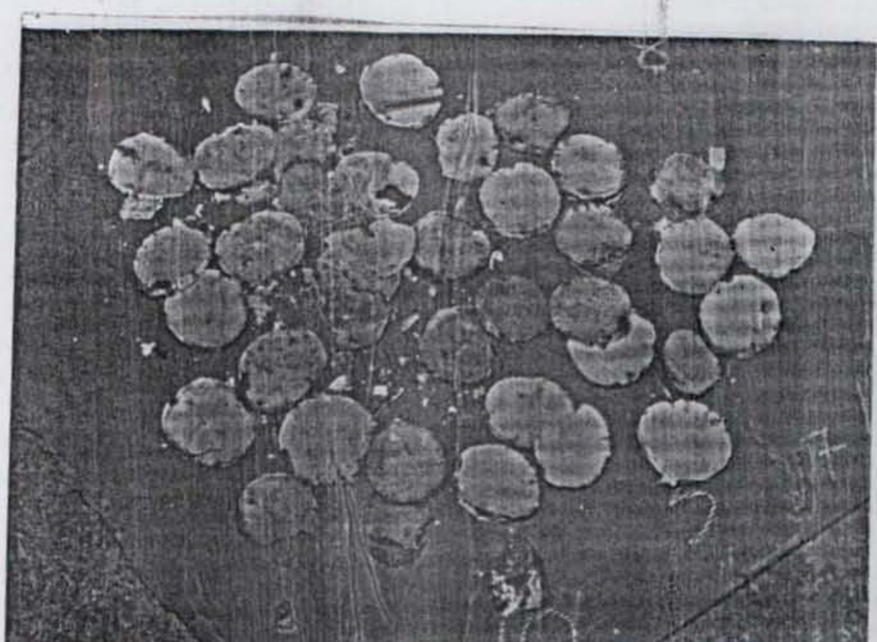


Plate 5: Round yam chips.

Journal of Agricultural Engineering and Technology (1996), 4,65-76

DEVELOPMENT AND CHARACTERIZATION OF PHOTO-RESPIROMETER

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ABSTRACT

The respirometer developed uses the carbon dioxide evolution to estimate respiration capacity of agricultural products. It is an indicating, self-contained (portable) powered instrument with lime water as the primary sensing element and the phototransistor as the transducer. Accuracy, precision and sensitivity of the instrument are high. The step response time leg is 12 seconds.

KEYWORDS

Photo-respirometer, Respiration-receiver.

1. INTRODUCTION

1.1 Respiration and Its Effects

Energy needs for organization and maintenance of life processes in plant cells is mainly from respiration. Respiration is a biochemical process in which food substrates in plants are oxidized. Oxidation is a sequence of enzyme-controlled reactions in which energy contained in the food is released, a little at a time (Ting, 1982). Net result of respiration is production of cell utilizable energy, release of carbon dioxide evolution of heat and formation of water vapour. For crops in storage, respiration is their major metabolic process and the source of energy for maintenance of cell life.

Though the respiration process is vital to life, it can complement life adversely, if uncontrolled. The condition is more noticeable with crops in storage. Excess heat and water vapour produced during uncontrolled respiration influence product storability. If the excess heat builds up within the storage environment, it may increase the temperature of the product above its optimal level. Metabolism in living tissue is a function of environment and product temperature. The higher the temperature, the higher the rate of metabolism. Also, differential increase in micro environmental temperature will create hot spots within the store that will eventually encourage mould growth or product moisture loss. Water vapour influences the relative humidity of the store, directly. Excessive reduction of the humidity results to excessive product moisture loss and accompanying shriveling or dehydration or shrinkage. But, excessive induction of the water vapour implies increase in moisture content which creates a favourable environment for higher water activity of the enzymes and micro-organisms. This will result in increased pathological damage.

Uncontrolled respiration can as well result in changes of oxygen or carbon dioxide concentration. High oxygen concentration may step up the rate of metabolism and thereby release the energy faster than it is necessary. This condition will increase the rate of breakdown of the food substrate in the product, which means increased rate of product weight, lesser shrinkage. High carbon dioxide concentration exerts narcotic influence on the plant cell and may depress respiration below the desired level.

Knowledge of product respiration rates and characteristics are therefore important since they serve as standards and control measures for the products and their environments and also design factors for storage structures. Such study will be done with such instruments as described in the study.

1.2 Respiration Measuring Instrument

Apart from comparing variables with determined standards, measuring instruments are also used for:

- monitoring processes and operations

- controlling processes and operations
- experimental engineering analysis design

Respiration is a physiological process, so a respiration meter could be used to monitor physiological change in crops while in the field, in storage or in laboratory. If connected to a control system, it will serve as a control to both the crop and the environment (storage space).

A number of researchers have used various methods to conform and estimate respiration and respiration capacities of agricultural products. The methods include the use of:

- manometers for measurement of changes in gas pressure
- alkalis for estimation of weight increases
- infrared carbon dioxide analyzers for determination of changes in carbon dioxide content
- paramagnetic oxygen analyzers and polarographic electrodes that are sensitive to molecular oxygen (Stratford, 1973; Sturt and Cockburn, 1972; Noggle and Fritz, 1976).

These methods are either cumbersome or are expensive and sophisticated to handle. The objective of this paper is therefore to develop and characterize portable, cheap and easily operating respirometer mainly for laboratory works.

2. PHOTO-RESPIROMETER DEVELOPMENT

Some meters measure properties that are related to the quantity of interest from where the desired parameters are deduced. The respirometer developed utilizes carbon dioxide evolved from respiration processes as the primary input quantity and lime water as the primary sensing element. The reaction of the carbon dioxide with the lime water ($Ca(OH)_2$) turns the clear solution milky and also increases its weight because of the formation of calcium carbonate and water. The weight increase is small and requires very sensitive balances to detect, hence the colour change of the solution was considered a better alternative for estimating the quantity of the gas that dissolved in the solution. In order to have a more objective and sensitive estimate of the colour change, an electrical system that is capable of converting light intensity to an electrically measurable quantity was considered as an integral part of the instrument. The components of the instruments are as shown in Fig. 1.

Respiration Receiver (RR): It is a cylindrical, transparent, thermosetting plastic container in which the primary sensing element (lime water) is contained. It is provided with a tight fitting cover on which is a hook for hanging the sample product whose respiration is to be estimated.

Light Source (LS): This includes a torch-light bulb enclosed in a 20mm diameter and 40mm length pipe attached to one end of an open top 150 x 50 x 50mm metal box in which are dry cell batteries for powering the bulb. In front of the bulb is positioned a converging lens for concentrating the light from the bulb to the RR.

Phototransistor Circuit (PC): This circuit is a one stage amplifier configured in Darlington mode with the phototransistor collector connected to the BC 108 and the emitter connected to the positive end of PC power source through a resistor in series. From the transistor collector, the circuit is connected to the negative end of the PC power source through a resistor as well and then to ma meter as shown in Fig. 2. The whole PC is arranged on a circuit board.

Housing: The LS, RR and PC are enclosed in a wooden housing of 480 x 480 x 200mm. Wood was used because of its low light reflectance. The PC meter is positioned on the outer side of the PC end of the housing to enable reading without opening the box. The door of the housing is at a point where each section of the unit could be reached with ease. All the units are in single line arrangement in the housing. The RR is between LS and PC. The LS bulb and PC phototransistor are at the same height but below the normal level of the lime water in the RR. The LS and PC have different power sources and different switches.

2.1 Working Principles of the Instrument

The product whose respiration capacity is to be determined is suspended in RR which already contains lime water. The product in question need not touch the solution. The carbon dioxide that is evolved from the product will turn the clear solution milky. With the RR and its contents in position within the instrument, and the door of the housing shut to shut off much of the external light, the circuit is switched on. The light will directly strike on the RR. Through the RR, the light illuminates the phototransistor surface from where electrons are ejected. The amount of light from the LS will be attenuated proportionately to the turbidity of the lime water. The amount of current send out from the phototransistor is proportional to the intensity of the light. And the light intensity is a function of the colour of the solution.

3. CHARACTERISITICS OF THE INSTRUMENT

3.1 Operational Characteristics

The photo-respirometer is an indirect variable measuring, deflection type instrument with an active transducer. The functioning pattern is illustrated in the block diagram in Fig. 3. The instrument measuring process begins with the lime water receiving the evolved respiration gas and changing its colour from clear to milky. At the next stage, light from the LS, amplifies the solution colour intensity. The modified light intensity is received on the surface of the phototransistor (instrument transducer). The light intensity is at this stage converted to an electrically measurable quantity – current. The quantity is manipulated and transmitted by the resistors and transistors (Fig. 2) to the display scale (PC meter). The instrument produces analog signals. As long as the product is respiring within the instrument chamber, it will keep sending continuous buy varying signals to the display element. But, it could be seen to be digital if it is switched off and one at intervals. Again, the rate of calcium hydroxide reaction with the carbon dioxide, which determines the variation in intensity, is slow therefore the rate of change of the signal will be slow to the point where it will be seen as if it is a digital response.

The interfering inputs to the instrument may be from:

- misalignment of the machine
- varying colour and thickness of respiration receiver (RR) and its content
- the distances between the light bulb and the RR, and the phototransistor and the bulb
- the level of lime water in the RR vis-a-vis the heights of the light bulb and the phototransistor

The modifying input will be due to:

- rate of reaction in the RR
- battery drain (efficiency of power source)
- variation of some internal component with increased usage.

3.2 Calibration

Calibration is the procedure of applying to an instrument transducer known values of the quantity to be measured and marking the output. It is a known and reproducible input/ output relationship with defined limits of accuracy under specified conditions. A calibration instrument should have numbers of some other symbols arranged on it to indicate the value of the conditions or quantity being measured. It can also be in form of charts or mathematical expression that relates the instrument meter reading to the input quantity. As a deflection instrument the accuracy of the photo-respirometer depends on the degree of accuracy of the calibration.

Calibration Procedure: The calcium hydroxide for the experiment was prepared by adding 5ml of water to 400g of calcium oxide. The lump of the quick lime crumbled to fine powder and eventually dissolved completely giving a clear solution. The solution was later filtered to get a very clear solution that was transferred into the respiration receiver (RR) of the instrument. The carbon dioxide was metered into the RR on the average of about 2.5mg at a time. At the end of each metering, RR and its contents were weighted with an electronic balance to determine the input quantity (q_i). Thereafter, it is inserted into the machine and the meter was read (q_o). Each of the instrument reading was repeated three times at intervals of 15 minutes before more gas was added. Before each instrument reading was taken, the switches of the machine were put on without the RR in the machine. This is to determine the maximum deflection of the machine because it gives indication of the battery efficiency.

Forty readings obtained were presented graphically in Fig. 4. The readings gave a power law relationship presented in Equation 1.

$$q_o = 1.46q_i^{\ 0.7078} \tag{1}$$

Static Characteristics: By definition, these are properties of an instrument that are considered when the machine is measuring quantities or conditions that are not varying with time. Among them is accuracy, precision, reproducibility and sensitivity. The undesired characteristics, which are in a sense, the reverse of those mentioned above are static or inaccuracy, drift, dead zone and others.

Accuracy and Static Error: The conformity or agreement of instrument indicated value to the accepted standard or true value of the measured variable is the accuracy of the instrument, while error is the deviation of instrument indicated value from the value of the measured variable (Eckman, 1961). Instrument condition that causes systematic error (bias) and random error (impression) impair accuracy. Accuracy is expressed as the degree of error in the instrument indicated value. The error curve of the instrument was plotted using the general static error value of each of the indicated points (Fig. 5). The percentage error per span of the indicated value was plotted against the percentage per span of the static error value (q_o (cal) – q_o (obs)). The error band of the calibration is $\pm$1.625% span.

Precision: Precision refers to closeness of a set of data taken at some value by same instrument under the same conditions. This is a characteristic that is dependent on random error. Table 1 shows part of the readings taken for calibration from various segments. Calculation based on the table shows that the instrument has about 1.25% degree of precision.

Static Sensitivity: It is the rate of change in the instrument scale, register or indicator (output) to change of input that caused it at a specified load or excitation level after attaining steady stage. It is equivalent to the slope of the calibration curve, i.e.

$$\text{Static sensitivity} = \frac{dq_o}{dq_i} = \frac{1.026}{q_i^{0.2972}} = 1.026q_i^{-0.2972} \tag{2}$$

From the expression, it implies that sensitivity decreases as input value increases. Vegetable that respires at high rate produces on the average about 50mg of carbon dioxide in six days. From Equation 2, sensitivity of the photo-respirometer at that point is 0.64%. This implies that the meter pointer will move by about 60% of an angle for every one milligram of carbon dioxide added. This movement can still be noticed by a careful eye.

Dynamic Characteristics: Fidelity, speed of response, dynamic error and lag are the properties that are xhibited by an instrument when subjected to input that is varying with time or input in cyclic or transient condition. These are referred to as dynamic characteristics.

The photo-respirometer transducer is a photocell. The number of electrons ejected per second from a photocell is proportional to the intensity of the incident radiation, i.e.

$$\frac{dq_o}{dt} = b.\quad I = bq_i \tag{3}$$

Table 1. Precision Estimation

CO_2 wt (mg)	Meter Reading		
	I	II	III
2.29	2.65	2.60	2.66
5.20	5.12	5.10	5.10
7.44	5.35	5.35	4.95
13.50	9.10	9.09	9.09
15.64	10.00	10.00	10.00
24.10	12.55	12.55	12.54
27.08	14.00	14.00	14.00
33.75	17.36	17.00	17.35
48.23	22.75	222.75	22.75

where the PC circuit has other transistors and resistors that are to amplify the current before it is indicated on the meter. Assuming that the amplification and transmission function is expressed by the factor a, the dynamic behaviour of the instrument can be expressed in the form:

$$\frac{a_i dq_o}{dt} + a_o q_o = bq_i \tag{4}$$

This is a linear differential equation with separate variables. From Equation 4,

$$a_i/a_o = T = \text{time constant (lag)}$$

$$b/a_o = K = \text{static sensitivity.}$$

The dynamic behaviour of instruments are determined by subjecting the primary element to step, linear (ramp) and sinusoidal changes.

Step Response: Here, the primary element of the instrument is subjected to instantaneous and finite change of the measured variable. This is the reaction that will be expected from the photo-respirometer each time.

Equation 4 can be re-written as:

$$\frac{Tdq_o}{dt} + q_o = q_i \tag{5}$$

The solution to Equation 5 is:

$$\ln (q_i - q_o) = t/T + A$$

where A is an integration constant. If initial boundary conditions are $q_o = 0$ at $t = 0$, the particular solution is:

$$q_o = q_i(1 - C^{-t/T})a \tag{6}$$

This represents a single exponential response. From Equation 6, if $t = T$,

$$q_o = 0.6321 q_i$$

Readings obtained from 10mg of carbon dioxide subjected to step function are indicated in Fig. 6. From the graph, the lag coefficient or time lag of the instrument (T) is 12 seconds. This is also a function of speed response. The dynamic error which is numerically equivalent to $(q_o - q_i)$ varies with time.

4. CONCLUSION

1. The sensing element of the photo-respirometer are the lime water, *light intensity, phototransistor and* transistors.
2. The input/ output relationship is $q_o = 1.46q_i^{\,0.7078}$
3. The calibration static error band is $\pm$1.625% of span and precision is $\pm$1.25%.
4. Dynamic step response time lag is 12 seconds.

5. NOTATIONS

A	-	integration constant
a_o, a_i	-	amplification and transmission factors
b	-	intensity factor
d	-	small change
I	-	intensity of incident radiation
K	-	static sensitivity
LS	-	light source
PC	-	phototransistor circuit
q_i	-	input
q_o	-	output
q_o (cal)	-	calculated output
q_o (obs)	-	observed output
RR	-	respiration receiver
T	-	time constant or lag coefficient
T	-	time

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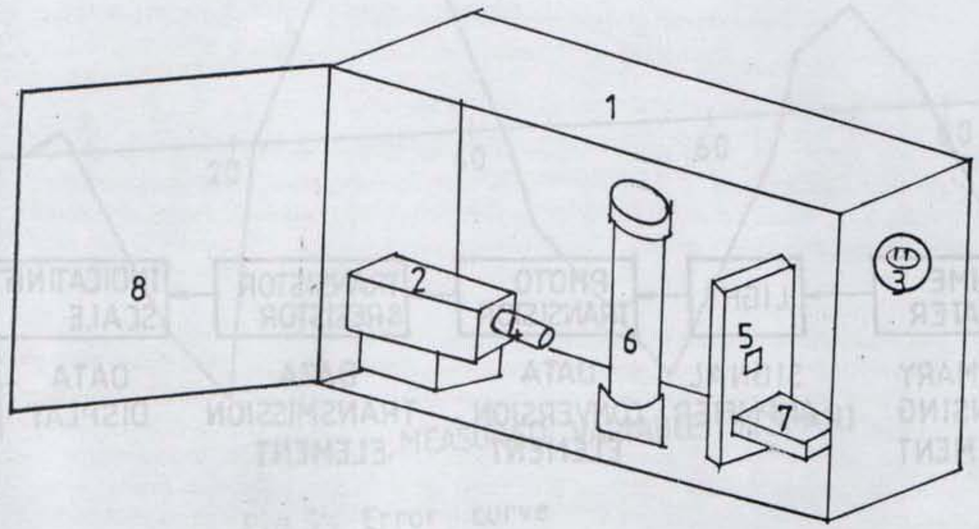
Fig. 1

Fig. 2



1-HOUSING 2-LIGHT BOX 3-METRE 4-BULB HOLDER 5-PHOTOTRANSISTOR
6-RESPIRATION RECIVER (RR) 7-CIRCUIT BOARD 8-DOOR

Fig. 1 Photo-respirometer

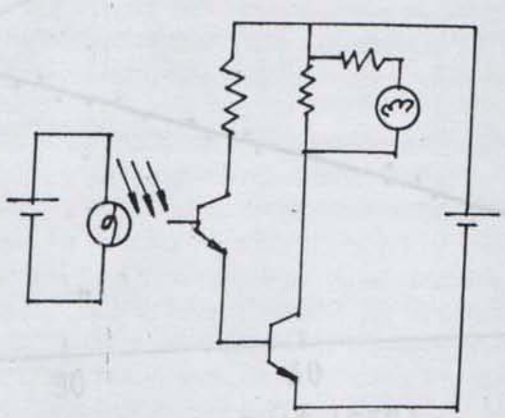


Fig. 2: Circuit diagram

Fig. 3

Fig. 4

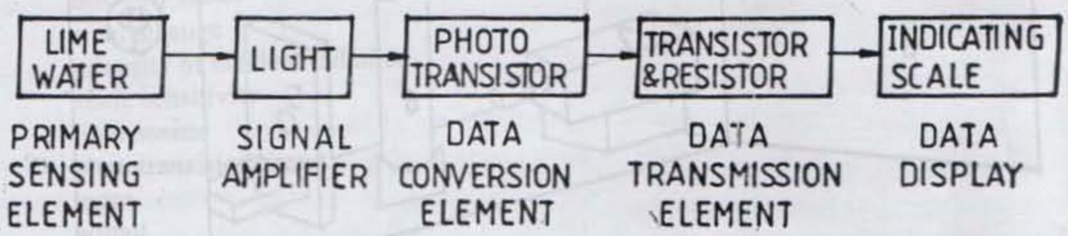


Fig. 3 : Instrument funtional elements

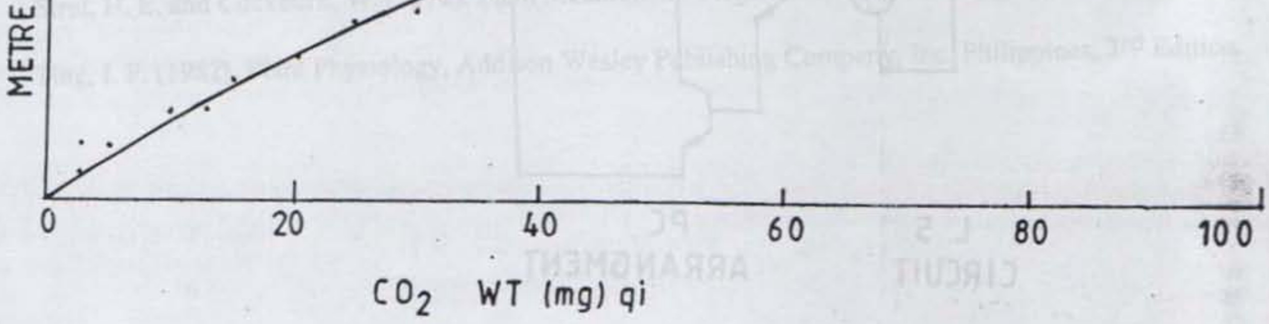


Fig. 4 : Calibration curve

Fig. 5
Fig. 6

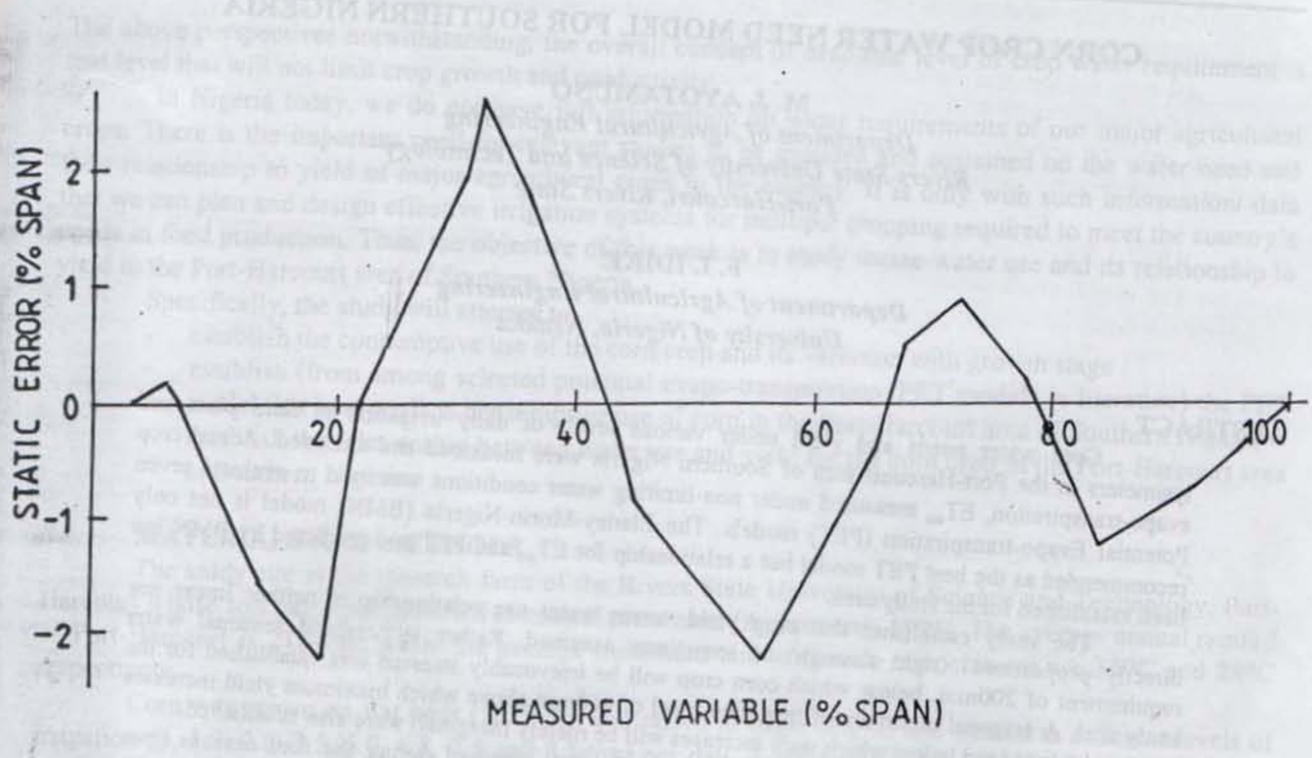


Fig. 5: Error curve

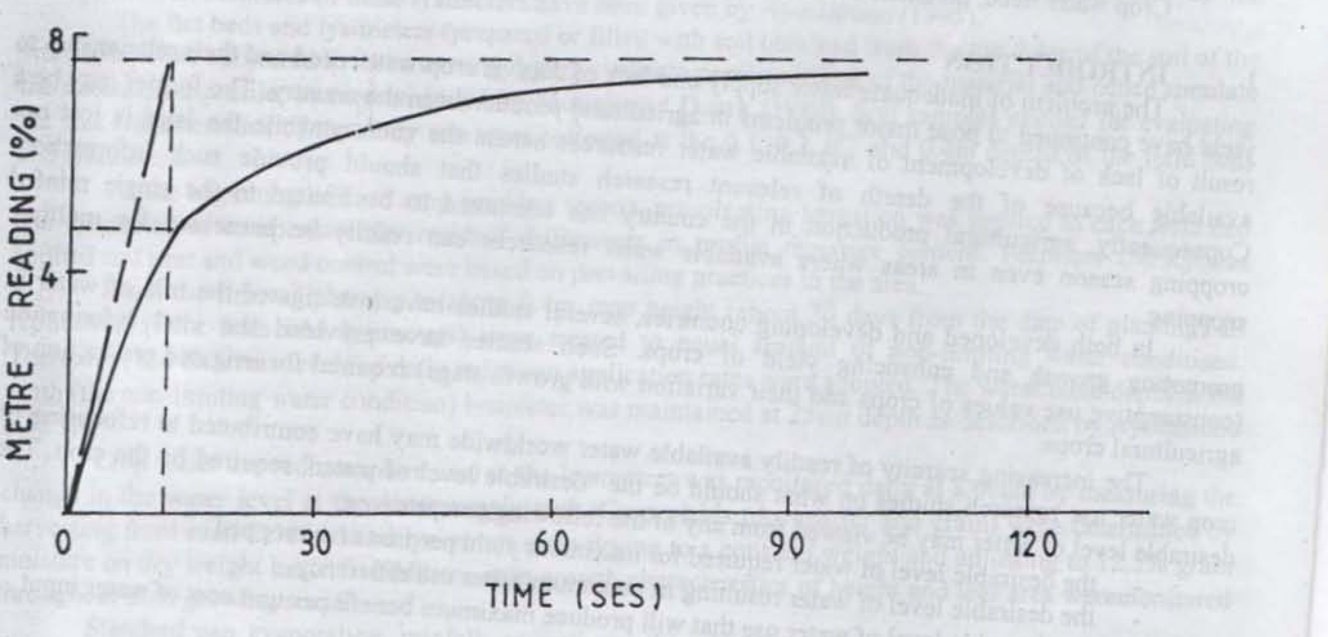


Fig. 6: Step change response

Journal of Agricultural Engineering and Technology (1996), 4,74-81

CORN CROP WATER NEED MODEL FOR SOUTHERN NIGERIA

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ABSTRACT

Corn water needs and yield under various levels of daily irrigation in field plots and lysimeters in the Port-Harcourt area of Southern Nigeria were measured and analyzed. Actual crop evapo-transpiration, ET_{act} measured under non-limiting water conditions was used to evaluate seven Potential Evapo-transpiration (PET) models. The Blaney-Morin-Nigeria (BMN) model is not only recommended as the best PET model but a relationship for ET_{act} and PET and predicted by BMN has been established for the study area.

The study establishes that crop yield versus water use relationship is neither linear nor directly proportional (right through) as sometimes assumed. Rather a threshold seasonal water requirement of 200mm, below which corn crop will be irrevocably stressed was established for the study area. A seasonal minimum of irrigation level of 460mm above which maximum yield increases will be obtained (and below which such increases will be merely marginal) were also established.

Based on the maximum crop water use efficiency obtained during the four seasons (two years) study a seasonal water requirement of 460 – 490mm is recommended for corn production in the Port-Harcourt area of Southern Nigeria.

KEYWORDS

Crop water need, potential evapo-transpiration, crop yield.

1. INTRODUCTION

The problem of inadequate water supply and lack of data on crop water need and their relationship to yield have continued to pose major problems in agricultural production in the country. The former may be a result of lack of development of available water resources across the country while the later is just not available because of the dearth of relevant research studies that should provide such information. Consequently, agricultural production in the country has continued to be limited to the single rainfed cropping season even in areas where available water resources can readily be harnessed for multiple cropping.

In both developed and developing countries, several studies have investigated the role of water in promoting growth and enhancing yield of crops. Such studies have provided the vital information (consumptive use values of crops and their variation with growth stage) required for irrigated production of agricultural crops.

The increasing scarcity of readily available water worldwide may have contributed to refocusing of crop water use research studies on what should be the "desirable level of water" required by the crop. The desirable level of water may be viewed from any of the following perspectives:

- the desirable level of water required for maximum yield per unit area cropped
- the desirable level of water resulting in maximum water use efficiency
- the desirable level of water use that will produce maximum benefit per unit cost of water input

The above perspectives notwithstanding, the overall concept of desirable level of crop water requirement is that level that will not limit crop growth and productivity.

In Nigeria today, we do not have full information on water requirements of our major agricultural crops. There is the important need for relevant studies to be initiated and sustained on the water need and their relationship to yield of major agricultural crops in the country. It is only with such information/ data that we can plan and design effective irrigation systems for multiple cropping required to meet the country's needs in food production. Thus, the objective of this work is to study maize-water use and its relationship to yield in the Port-Harcourt area of Southern Nigeria.

Specifically, the study will attempt to:

- establish the consumptive use of the corn crop and its variation with growth stage
- establish (from among selected potential evapo-transpiration, PET models in literature) the PET model that best predicts consumptive use of corn in the Port-Harcourt area of Southern Nigeria
- establish the relationship between water use and yield for the corn crop in the Port-Harcourt area of Southern Nigeria.

2. MATERIALS AND METHODS

The study site is the research farm of the Rivers State University of Science and Technology, Port-Harcourt whose soil has been classified as coastal plain sand (Ayotamuno, 1995). The average annual rainfall of Port-Harcourt is 2184mm while the average maximum and minimum temperatures are 36^oC and 28^oC respectively.

Corn was grown on flat beds (1m x 1m and raised to 0.6m height) and treated to different levels of irrigation (0, 1.0, 2.0, 3.5, 5.0, 6.5, 7.5 and 8.5mm) per day. A split plot in completely randomized design with three replications for each level of irrigation was adopted giving a total of twenty-four flat beds arranged three beds per row. Eight non-weighing water table lysimeters, one for each level of irrigation was constructed as galvanized cubical steel tanks (70 x 70 x 70cm^3) and used as control for the field bed study. A ninth and similar lysimeter located around the University meteorological station was used to determine daily crop evapo-transpiration (consumptive use) ET_{act} under non-limiting water condition. Details of the construction and features of these lysimeters have been given by Ayotamuno (1995).

The flat beds and lysimeters (prepared or filled with soil obtained from the top 0.4m of the soil of the study site) were subjected to three wetting drying cycles to permit settling of the material and hence simulate the natural soil profile, as recommended by Musick and Dusek (1980). Soil samples needed for evaluating the soil characteristics of the study site were collected at the 0.1, 0.2, 0.3 and 0.4m depths of the field beds and lysimeters.

At the beginning of each crop growing season, pre-planting irrigation was applied to each field bed and lysimeter to compensate for residual differences in profile moisture content. Fertilizer (NPK) was applied and pest and weed control were based on prevailing practices in the area.

From the time of planting to about 0.4m crop height (about 30 days from the date of planting) all replication (field beds and lysimeters) were treated to equal amount of non-limiting water conditions. Thereafter, the different levels of daily irrigation application rates were adopted. The water table depth in the ninth (the non-limiting water condition) lysimeter was maintained at 25cm depth as described by Ayotamuno (1995).

Crop water use (consumptive use) in the lysimeters was monitored daily at 8.00am by measuring the change in the water level at the water supply tank. Crop yields (dry-matter and grain) were determined by harvesting from each field bed and lysimeter; oven-drying to a constant weight and adjusting to 12.5% grain moisture on dry weight basis. In addition, crop growth characteristics of height and leaf area weremonitored throughout each growing season.

Standard pan evaporation, rainfall, as well as other climatic /meteorological data required by the selected PET models (Penman, Blaney-Morin-Nigeria (BMN), Class A Pan, Thornthwaite, Blaney-Cradle, Hargreaves and Jensen-Hayes) were measured daily at the University Meteorological Station. These climatic/meteorological data for a ten-year period (1983-1992) were also obtained fro the meteorological station and their average values were adopted as the normal values for the study area.

All information and data obtained during the study as well as the predictions of PET by the various PET models studied were analyzed statistically. The field study lasted for two years – 1993 and 1994 – with two crop growing seasons each year (February – May and September – December in 1993 and January – April and September – December in 1994).

3. RESULTS

The physical characteristics of the sandy loam soil of the study site as determined by laboratory analysis include:

Field capacity	13.66%
Wilting point	6.21%
Available water	46.70mm
Bulk density	1.6 g/cm^3
Water holding capacity	133.30mm

The available water given above is based on the root zone depth of corn in the study site which is taken as 33.0cm.

Table 1 shows that except for the rainfall the major climatic conditions of the study area during the two-year period maintained the normal trend. The 1993 study year was much drier than the normal trend for the Port-Harcourt area of Southern Nigeria.

Table 2 presents the crop water use under non-limiting water conditions for the distinct growth stages usually associated with agricultural grain crops. The specific characteristics of these growth stages for corn in the Port-Harcourt area were established as: establishment stage (22 days), vegetative stage (29 days), pollination stage (19 days) and grain filling stage (23 days). The values of the crop growth characteristics (leaf area and plant height) presented also in Table 2 are the mean values measured at the end of each stage. The leaf area is the product of the length from the base to the tip and the maximum width.

The pollination and grain-filling stages show equal leaf areas since leaf area growth stopped at the pollination stage.

Crop water use increased from a minimum during the establishment stage to a maximum during the vegetative stage and thereafter decreased. However, the highest daily crop water use occurred during the pollination stage with average daily values of 4.5, 4.9, 4.1 and 4.6mm during the four growing seasons of 1993 and 1994 when compared to average daily values of 5.4, 4.1, 3.4 and 3.1mm for the vegetative stage during the same periods. It will be recalled that Musick and Dusek (1980) had associated maximum corn crop water use with the pollination stage. The average seasonal consumptive use value for the four crops grown during the study is 313.3mm or 3.45mm per day.

Table 3 presents the average daily crop water use ET (lys) during the two years of study as well as the PET predictions (average values) by the selected PET models during the same period. The $ET_{act(lys)}$ values are the actual measured crop water use under non-limiting water condition and should not be expected to be equal to the PET values at all growth stages. However, the upper limit of the actual crop water use ET (lys) should tend to PET. The maximum crop water use during the first cropping seasons of the two years of study occurred in May/ April and in December during the second seasons. Based on the above, the raw values of Table 3 show that the BMN, Penman and Class A pan PET models, in that order, did a good job in predicting potential evapo-transpiration.

Statistical analyses show that the predictions by Penman and BMN were not significantly different at the 5% level using the Duncan Multiple Range Test. All other predictions were significantly different from each other at the same level and substantially different from the measured $ET_{act(lys)}$. Consequently, the Penman and BMN models are considered suitable for use in the study area.

The crop coefficients computed using Table 3 show that the Penman model-determined crop coefficients were slightly higher while others (except the BMN determined values) were lower than reported in literature. The BMN determined values are much closer to those reported in literature thus enhancing the rating of the BMN model as a suitable model for the Port-Harcourt area.

Apart from the fact that the data required by the Penman model are numerous and more difficult to come by, the combined Jensen (1974) and Hargreaves and Samani (1982) procedures for ranking/ evaluating the accepted models (Penman and BMN) ranks BMN a better PET model for the study area and expresses actual crop evapo-transpiration under non-limiting water condition, ET_{act} as:

$$ET_{act} = 4.80 - 0.18PET_{bmn}$$

$$\text{and } ET_{crop} = K_c ET_{act}$$

where PET_{bmn} is potential evapo-transpiration (mm/day) computed using the Binary-Morin-Nigeria, BMN model, ET_{crop} is crop evapo-transpiration (consumptive use) at a given growth stage (mm/day) and K_c is the crop coefficient.

Table 4 presents the seasonal water applied, the crop yield and the water use efficiency during the four seasons of the study. The table reveals initial marginal increase in yield as irrigation level increased (T_0 to T_2); then rapid increase in yield with subsequent increase in irrigation level (T_2 to T_4) until the rate of increase begins to decrease with larger irrigation levels (T_4 to T_7).

At low irrigation levels (T_0 to T_1), the crops were observed to be generally stunted in growth; did not show any tasselling, pollination and silking and hence did not produce any grains. Grain production was observed in all cases beginning the T_2 water application level and this production increased rapidly with increase in water application level. Beyond the T_4 irrigation level this increase in yield with increase in irrigation level became marginal. It should be noted that the maximum water use efficiency occurred with the T_4 irrigation level for all seasons of the study. The maximum crop yield values occurred within the T_4 to T_7 irrigation levels.

Fig. 1 presents the regression of the crop yield on water use for the four seasons of the study. By locating the point immediately before the maximum crop yield boundary (T_4 to T_7) and projecting to the coordinate axes the minimum seasonal water requirement value above which maximum increases in crop yield will occur was found to be 430mm (February/ May 1993 growing season), 460mm (September – December 1993 growing season), 380mm (January – April 1994 growing season) and 400mm (September – December 1994 growing season). The unusually dry 1993 year has clearly reflected the climatic influence on water needs of the crop. The first and second seasons of 1993 and 1994 respectively should have shown the same (or at least similar) minimum seasonal values. Below the above minimum values, crop yield increases were found to be only marginal. A single value of 460mm is recommended for the study area. Fig. 1 also shows that the crop yield versus water use relationship is neither linear nor directly proportional right through. This is in line with the finding of Hillel and Buron (1993) which indicated a threshold water requirement value below which crop production is negligible. For this study, the threshold value was found to be 200mm. Hence, a seasonal irrigation water below 200mm will irrevocably stress corn crop in Port-Harcourt area of Nigeria. Based on the maximum crop water use efficiency (Table 4) a seasonal irrigation water of 460 – 490mm is recommended for corn in the Port-Harcourt area of Southern Nigeria.

4. CONCLUSION

Actual crop evapo-transpiration (for corn) measured in lysimeters in the Port-Harcourt area of South-eastern Nigeria was used to evaluate seven PET models. The BMN model is not only recommended as the best PET model for the study area but a relationship for actual crop evapo-transpiration ET_{act} and BMN_{bmn} has been established for the study area.

Corn crop water need and yield under various levels of daily irrigation in field plots and lysimeters were measured and analyzed. The analysis establish that the crop yield versus water use relationship is neither linear nor directly proportional (right through) as sometimes assumed. Rather a threshold seasonal water requirement of 200mm below which corn crop will be irrevocably stressed was established for the study area. A seasonal minimum of irrigation level of 460mm above which maximum yield increases will be obtained (and below which such increases will be merely marginal) was also established for the study area.

Based on the maximum crop water use efficiency obtained during the four seasons (two years) study, a seasonal irrigation water requirement of 460 – 490mm is recommended for corn crop production in the area.

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Table 1. Values of Major Climatic Parameters of the Study Area

Climatic Parameter	Crop Growing Season	
	Jan/Feb – April/May Cropping Season	Sept. – Dec. Cropping Season
Temperature (^{o}C) Normal (taken as 10yr average)	27.8	-26.6
1993 study year	27.9	27.3
1994 study year	28.0	26.8
Solar Radiation (cal/cm) Normal (taken as 10yr average)	751.5	676.8
1993 study year	768.2	694.8
1994 study year	780.4	710.7
Rainfall (mm) Normal (taken as 10yr average)	109.8	166.9
1993 study year	68.0	156.7
1994 study year	78.1	175.3

Table 2. Crop Water Use and Some Growth Characteristic at Various Growth Stages (Average Values)

Crop Growth Stage Identified by Days after Planting	Crop Water Use (mm)	
	Jan/Feb – April/May Cropping Season	Sept. – Dec. Cropping Season
Establishment 0 – 22 day	33.30 (0.04, 0.40)*	27.60 (0.05, 0.44)
Vegetative 22 – 51 day	108.80 (0.15, 1.49)	94.50 (0.15, 1.51)
Pollination 52 – 70 day	89.3 (0.17, 2.39)	81.20 (0.19, 2.49)
Grain 71 – 93 day	103.7 (0.17, 2.65)	88.4 (0.19, 2.70)
Seasonal Total 0 – 93 day	335.1 (0.17, 2.65)	291.8 (0.19, 2.49)

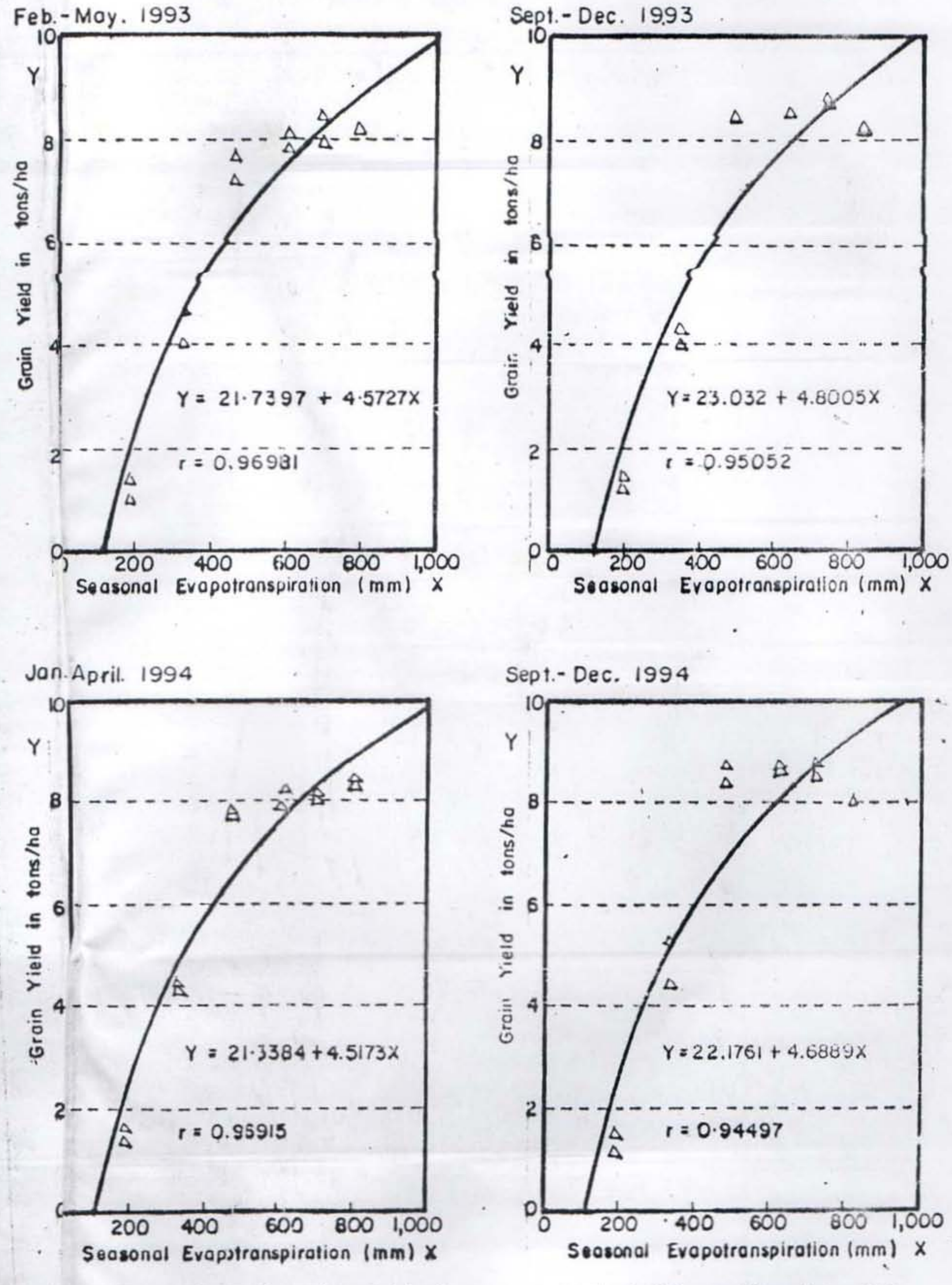
* the two values in parenthesis are the leaf area (m) and plant height (m) respectively.

Table 3. **Daily Crop Water Use ET(lys) and PET Predicted by the Selected PET Models (Average Values)**

Month of Year	Daily, Crop, Water, Use/ PET Values (mm/day)						Jensen & Haise
	ET(lys)	Renman	BMN	Class A Pan	Blaney & Criddle	Hargreaves	
Jan./Feb. – April/May Cropping Season							
Jan.	1.5	4.1	4.3	5.8	7.3	8.1	10.1
Feb.	2.8	3.9	4.5	5.0	6.4	8.0	10.7
Mar.	4.3	3.6	3.9	4.0	5.8	8.0	10.0
April	4.6	3.5	3.8	3.7	6.5	8.2	10.3
May	3.8	3.2	3.2	33.8	6.5	7.6	9.5
Seasonal	3.7	3.7	4.1	4.4	6.5	8.0	10.3
Sept. – Dec. Cropping Season							
Sept.	0.5	3.3	2.7	4.2	7.3	7.8	9.7
Oct.	2.0	2.6	2.7	3.5	6.0	6.7	8.3
Nov.	3.8	2.9	3.2	4.1	5.9	7.6	9.4
Dec.	3.5	3.4	3.3	4.7	5.9	6.7	8.3
Seasonal	3.0	3.0	3.0	4.1	6.0	7.0	8.7

Table 4. **Seasonal Average Values of Irrigation Water Applied, Crop Yield and Water Use Efficiency**

Daily Irrigation Treatment (mm/day)	Total Seasonal Water Applied (mm)	Yield (tons/ha)						Water Use Efficiency x 1000
		Dry Matter			Grain			
		Field Plots	Lysimeters	Mean	Field Plots	Lysimeters	Mean	
Jan./Feb. – April/May Cropping Season								
T_o (0)	0.0	0.05	0.05	0.05	0.0	0.0	0.0	0.0
T_1 (1.0)	93.5	0.13	0.12	0.13	0.0	0.0	0.0	0.0
T_2 (2.0)	187.0	3.39	3.93	3.66	1.05	1.51	1.28	0.68
T_3 (3.5)	328.0	13.75	13.68	13.70	4.39	4.21	4.30	1.32
T_4 (5.0)	468.0	17.54	17.71	17.62	7.39	7.93	7.666	1.61
T_5 (6.5)	608.0	17.23	18.23	17.75	7.79	8.11	7.93	1.30
T_6 (7.5)	700.0	17.81	18.63	18.44	7.76	8.10	7.93	1.15
T_7 (8.5)	795.0	18.08	17.90	17.94	8.13	8.32	8.23	1.04
Sept. – Dec. Cropping Season								
T_o (0)	0.0	0.04	0.03	0.04	0.0	0.0	0.0	0.0
T_1 (1.0)	97.0	0.13	0.14	0.14	0.0	0.0	0.0	0.0
T_2 (2.0)	194.0	3.27	3.75	3.51	1.06	1.47	1:26	0.66
T_3 (3.5)	340.0	14.21	14.08	14.15	4.50	4.63	4.57	1.35
T_4 (5.0)	485.0	18.747	19.10	18.94	7.43	3.54	8.49	1.75
T_5 (6.5)	631.0	19.77	18.85	19.31	8.6	8.54	8.57	1.37
T_6 (7.5)	728.0	18.88	19.28	19.08	8.48	8.56	8.52	1.20
T_7 (8.5)	825.5	18.48	19.07	18.78	8.07	8.13	8.10	0.99



Fi . Regressiors of grain yield of corn on actual ET resulting from the four irrication seasons (1993 — 1994) Port Harcourt area.

JOURNAL OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
VOLUME 4, 1996

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