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CONTENTS

Planning For Water Quality In Rural Environments Using Wrm Model — 1
- Constantine C. Mbajiorgu

Spatial Variability Of Maize Yield And Soil Properties On An Eroded Landscape In Southern Nigeria — 13
- H. O. Fapohunda, D. J. Oyedele and P. O. Aina

Evaluating Surface Irrigation System Under Highwatertable Conditions — 25
- O.J. Mudiare and M.K. Dalhat

The Effects Of Nitrogen Solubility Of Heat Processing Alfalfa Herbage — 37
- Y.D. Yiljep, W.K. Bilanski and D.N. Mowat

A Device For Shear Fracture Evaluation Of Soybeans — 50
- C.N. Asota

An Evaporative Cooling System For Rural Storage Of Fresh Tomato — 56
- Ndirika, V.I.O. and C.N. Asota

Development Of Whole Crop Cowpea Thresher As Affected By Grain And Stalk Properties — 67
- E.I.U. Nwuba, E.A. Arinze and F.G. Braide

Development And Performance Evaluation Of A Millet Thresher — 80
- V.I.O. Ndirika

Pedal Operated Chipping And Slicing Machine For Tubers — 90
- A.O. Rajiand J.C. Igbeka

J. Agric. Engng and Techn. (1994) 2 1-12

PLANNING FOR WATER QUALITY IN RURAL ENVIRONMENTS USING WRM MODEL

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Abstract.

Degradation of surface water quality ranks high amongst the off-farm costs of soil erosion, which result from non-point source pollution by chemical laden sediments. A model has been developed to predict, amongst other things, the sediment load at any location in the drainage network of an agricultural watershed. Watershed Resources Management (WRM) model, as it is named, is a process-based, distributed-parameters model for continuous simulation. It models sediment flow in a watershed that may include conservation structures, such as terraces, grassed waterways, dams and culverts, by the flow transport capacity concept. Fundamental erosion and hydrological processes are represented in WRM model components.

This paper presents the erosion and sediment transport components of WRM model development. In addition, the model was applied to predict sediment flow under different hypothetical scenarios of conservation measures for an agricultural sub-watershed in the Upper-Wilmot River Basin, prince Edward Island, Canada. Model results, as presented, compare favourably with observation and common knowledge, thus validating WRM model for the specific application. Model evaluation, based on predicted effects of the simulated conservation measures, also shows a reasonable model performance.

KEYWORDS: Erosion, Sediment-transport, Non-point source pollution, Water quality, Conservation practices, Water resources planning, Distributed-parameter modelling, Watershed.

1. INTRODUCTION

The most distinctive water quality problem in rural environments is non-point source pollution. This may be defined as the contamination of water resources by sediments, fertilizers, pesticides and natural soil chemical constituents, transported by runoff water from distributed locations on the watershed. Rural land-use practices, being agricultural, tend to exacerbate the problem. Information of adequate quantity, accuracy, and variability in time and space, which may be required to treat and regulate/control non-point source pollution are best provided by predictive tools. Sampling and analyses of water pollutants from distributed sources on agricultural land are formidable tasks. They can be justified only for the purposes of model calibration and testing.

Traditionally, sediment yield has been predicted by applying a delivery ratio to gross erosion. However, delivery ratio is a lumped and unreliable technique. Water quality modelling requires a shorter time scale than annual, and cannot be separated from the pollutant transport processes which are driven by hydrology.

The universal soil loss equation was modified by Williams (1975), by replacing the rainfall energy factor with a runoff factor. The modified universal soil loss equation (MUSLE), increased sediment yield prediction accuracy, thus eliminating the need for sediment delivery ratios, and is applicable to individual rainfall events. However, it relies on measured runoff for its accuracy, and measured runoff is almost never available in water resources planning. Therefore, the process-based and distributed modelling approach is preferable. Such a model, the Watershed Resources Management (WRM) model (Mbajiorgu, 1992), facilitates a synthesis of the hydrologic, soil erosion, sediment transport and structural component processes in both temporal and spatial variability. This paper presents the sub-models for erosion and sediment transport, and typical results of WRM model application in predicting sediment quantities in stream flow under different conservation-practice scenarios.

2. Development Of The Soil Erosion And Sediment Transport Components Of Wrm Model

Erosion and sediment routing are based on routed hydrologic inputs at each location on the watershed. Six proceses are involved, namely: (1) Rainfall (interrill/splash) detachment, D_i; (2) Overland/shear flow detachment, D_f; (3) Overland flow transport, T_c (for capacity value); (4) Channel and reservoir deposition, Dep; (5) Channel entrainment of deposits, E; and (6) Channel flow transport, Q_s (for capacity value).

Erosion can be defined as the change in sediment load accross an element, subject to soil detachment and flow transport capacity, and may be expressed as follows:

$$\Delta G = (D_f + D_i)\Delta x \qquad (1)$$

where, G is sediment load (kg s^{-1} m^{-1}), x is distance downslope (m), D_i is interrill erosion rate (kg s^{-1} m^{-2}), and D_f is rill erosion rate (kg s^{-1} m^{-2}). After Foster (1982),

$$D_f = D_c[1 - G/T_c] \qquad (2)$$

where, Tc is sediment transport capacity (kg s^{-1} m^{-1}), and Dc is detachment capacity of clear water (kg s^{-1} m^{-2}). After Lane *et al.* (1987).

$$D_c = K_r(\tau_s - \tau_c) \qquad (3)$$

where, K_r is rill erodibility parameter (s m^{-1}), τ_s is flow shear stress acting on the soil (Pa), τ_c is rill critical shear stress of the soil (Pa), and D_i is interrill erosion rate (kg s^{-1} m^{-2}). The interrill erosion rate is given, after Foster (1982), as

$$D_i = K_i I^2 S_f C_e G_e \qquad (4)$$

where, Ki = interrill erodibility parameter (kg s m^{-4}), I is rainfall intensity (m s^{-1}), and Sf is slope factor. After Elliot et al. (1989).

$$S_f = 1.05 - 0.85e^{[-4\sin(s)]} \qquad (5)$$

where, s is slope angle (degrees) and C_e is canopy effect. After Nearing et al. (1989),

$$C_e = 1 - Fe^{-0.34H} \qquad (6)$$

where, F is fraction of soil surface under canopy cover, H is canopy height (m), and G_e is ground cover effect. After Nearing et al. (1989),

$$G_e = e^{-2.5f} \qquad (7)$$

where, f is fraction of soil surface covered by residue.

Elliot *et al.* (1989) and Liebenow *et al.* (1990) developed equations to predict erodibility parameters from soil properties. At any location on the watershed across which flow transport capacity T_c is greater than sediment load G, soil erosion will occur and as a result, sediment load will increase:

$$G_{i+1} = G_i + \Delta G \qquad (8)$$

This increase is subject to the condition, $(T_c - G_i)$: ΔG. If $(T_c - G_i) < \Delta G$, then $G_{i+1} = T_c$. Similarly, where $T_c < G_i$, $G_{i+1} = T_c$.

2.1 Overland Flow Transport Capacity (T_c)

Slope (S), unit discharge (q) and shear stress acting on the soil (τ_s) have been identified as factors for determining sediment transport capacity. But shear stress is a derived quantity incorporating both S and q. Therefore, τ_s is the single most important parameter for a simplified model for T_c. Finker et al. (1989) proposed a simplified equation for T_c based on the Yalin (1963) sediment transport equation as:

$$T_c = K_t \tau_s^{3/2} \qquad (9)$$

where K_t is the transport coefficient. Overland flow shear stress is expressed as:

$$\tau_s = \gamma f_s/(8g)^{1/3} f_t^{2/3} (qS)^{2/3} \qquad (10)$$

where, γ is weight density of water, f_s is Darcy-Weisbach hydraulic roughness coefficient for smooth, bare soil, f_t is hydraulic roughness coefficient for actual soil condition, q is overland flow discharge per unit width, and S is land slope.

Since f_s, f_t, γ and g are constants, τ_s is a function of q and S for a given upland area. The value of K_t is to be determined independently for each upland area, but no method is known for determining K_t directly from sediment properties. However, parameters of the Yalin equation can be estimated for determining T_c. This is essentially a calibration of the simplified equation to sediment properties. A representative shear stress (τ_{so}) is determined as the average of the shear stress at the end of a representative uniform average slope profile and is used to compute transport capacity by the Yalin equation. With this value of t_{so}, transport coefficient is computed as follows:

$$K_t = T_{co}/\tau_{so}^{3/2} \qquad (11)$$

where T_{co} is transport capacity computed from the Yalin equation using τ_{so}.

2.2 Channel Flow Deposition and Pick-Up

The regime concept in alluvial channel hydraulics states, after Ackers (1988), that the dimensions (width, depth and gradient) of a channel to convey a given discharge of flow with a given sediment load are fixed by nature. Thus depending on the flow discharge and its sediment load, deposition or scour will occur in the channel. The regime concept expresses the natural tendency for alluvial channels to seek a dynamic stability.

The difficulty in modelling channel scour arises due to bed features. The overallflow resistance in alluvial channels comprises both drag due to bed form (ripples and dunes) and drag due to bed material (grain resistance). Thus the critical shear parameter and channel erodibility cannot be easily evaluated. Therefore, pick-up of upland eroded deposits may be considered by assuming rill erodibility and critical shear parameters for channel flow. For the case $Q_s > G_l$ and $\tau_s > \tau_c$, pick-up is computed as,

$$E = K_r(\tau_s - \tau_c)\left(1 - \frac{G_l}{Q_s}\right) \qquad (12)$$

where, E is channel flow sediment entrainment and Q_s is its transport capacity. Sediment load, G, is updated as $G = G_l + E$. Otherwise deposition occurs if $Q_s < G_l$ and is estimated as, $Dep = G_l - Q_s$, while sediment load equals Q_s.

Flow shear stress assuming a wide, shallow open channel is,

$$\tau_s = \gamma y S \qquad (13)$$

where, $\gamma = \rho g$ or the weight density of water (ρ is density of water, g is gravity acceleration), y is flow depth, and S is channel bed slope.

2.3 Channel Flow Transport Capacity (Q_s)

Ackers (1988) lists the minimum set of basic quantities which influence sediment transport in two-dimensional, free-surface flow as follows: (1) unit mass or density of water, ρ; (2) unit mass or density of solids, ρ_s; (3) kinematic viscosity of water, υ; (4) particle diameter, d; (5) flow depth, y; (6) bed shear velocity, $V = gyS$; (7) gravity acceleration, g; (8) bed slope, S. These quantities are related by dimensional analysis in the following non-dimensional groups:

i) the Particle Reynolds Number;

$$Re = Vd/\upsilon \qquad (14)$$

ii) the Sediment Mobility Number;

$$Y = V^2/(s-1)gd \qquad (15)$$

iii) the ratio of flow depth to sediment diameter;

$$Z = y/d \qquad (16)$$

and, (iv) the mass densities ratio;

$$s = \rho_s/\rho \qquad (17)$$

Einstein's (1950) non-dimensional expression gives an additional parameter for establisned motion, for sediment load:

$$\phi = \frac{q_s}{\rho[(s-1)gd]^{3/2}} \qquad (18)$$

where q_s is sediment transport rate as weight per unit time per unit width of channel. The mobile bed friction factor is expressed in terms of the basic quantities as,

$$f_f = 8gyS/\upsilon^2 \qquad (19)$$

and the expression,

$$\phi f_f/4 = 0.1(Y^{5/2}) \qquad (20)$$

relates sediment transport and channel hydraulics, as formulated by Engelund and Hansen (1967).

Based on these relationships and assuming a representative particle diameter, such as mean weight diameter, a procedure for determination of Q_s is as follows: (1) Compute the parameter Y, as a function of flow depth and bed slope, from eqn. (15); (2) With the right-hand side of eqn. (20) evaluated, compute the parameter f_f from eqn. (20); (4) Evaluate q_s from ϕ, using eqn. (18); (5) Compute Q_s as equal to bq_s, where b is channel width.

3. MODEL APPLICATION FOR WATER QUALITY PLANNING

Comparison of continuous recorded and simulated stream flow hydrographs were performed for Curley's sub-watershed in the Upper Wilmot River Basin, Prince Edward Island, Canada. Curley's sub-watershed has an area of 140 ha. A duration of 5 months, May 5 to September 30, 1990, was covered by simulations. The small subset of model parameters, termed "calibration parameters", whose values may be adjusted to calibrate the model were used to obtain an order of magnitude agreement between simulated and recorded flows in the first rainfall event. The model was validated by comparison of simulated and recorded hydrographs for subsequent events in the series (Mbajiorgu, 1992).

Fig. 1 shows the discretization of the sub-watershed into square elements of size 1.94 ha, numbered serially from 1 to 73. The comparison of model validation hydrograph plots are shown in Figs. 2, 3 and 4. The plots were sampled from a single continuous simulation run, in the period May 5 to September 30, 1990. Visual comparison of simulated and recorded hydrographs shows an order of magnitude consistency and reasonable reproduction of system response features. Based on model validation criteria, as specified by Law and Kelton (1982), and with due consideration for the modelling assumptions, the WRM model was thus tentatively validated.

Using the discretization of Curley's sub-watershed shown in Fig. 1, the following soil and water conservation planning alternatives were implemented in simulation: (1) starting from element #9 every vertical grid-line represents a terrace channel, and every <u>other</u> horizontal grid-line represents a grassed waterway draining into a stream-channel reach; (2) two dams of uniform size and reservoir capacity are located in elements #36 and #70; (3) a dam is located in element #36 and a culvert already exists in element #55.

WRM model was used to quantify the effects, and relative effects, of the above hypothetical or "what-if" conservation planning scenarios, in terms of sediment load in streamflow. The reasonableness of such evaluated effects and relative effects, in the absence of real-world data, is adjudged to represent model evaluation.

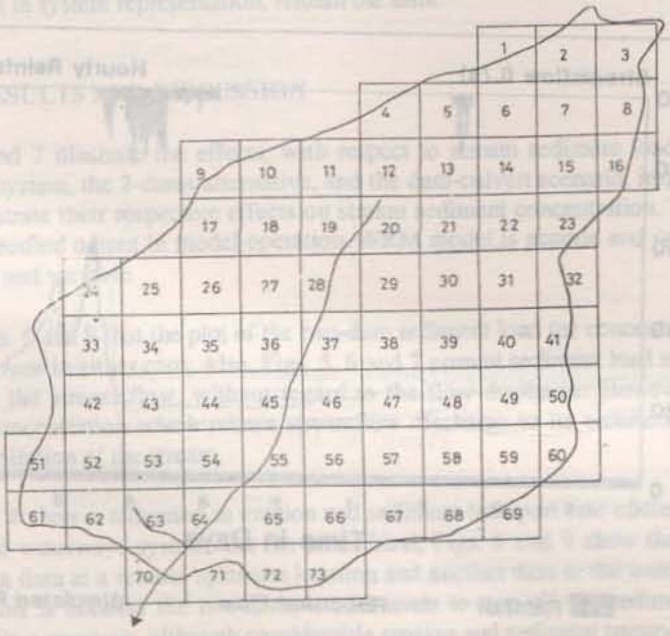

Fig. 1. Curley's sub-watershed discretization; scale 1:8,705

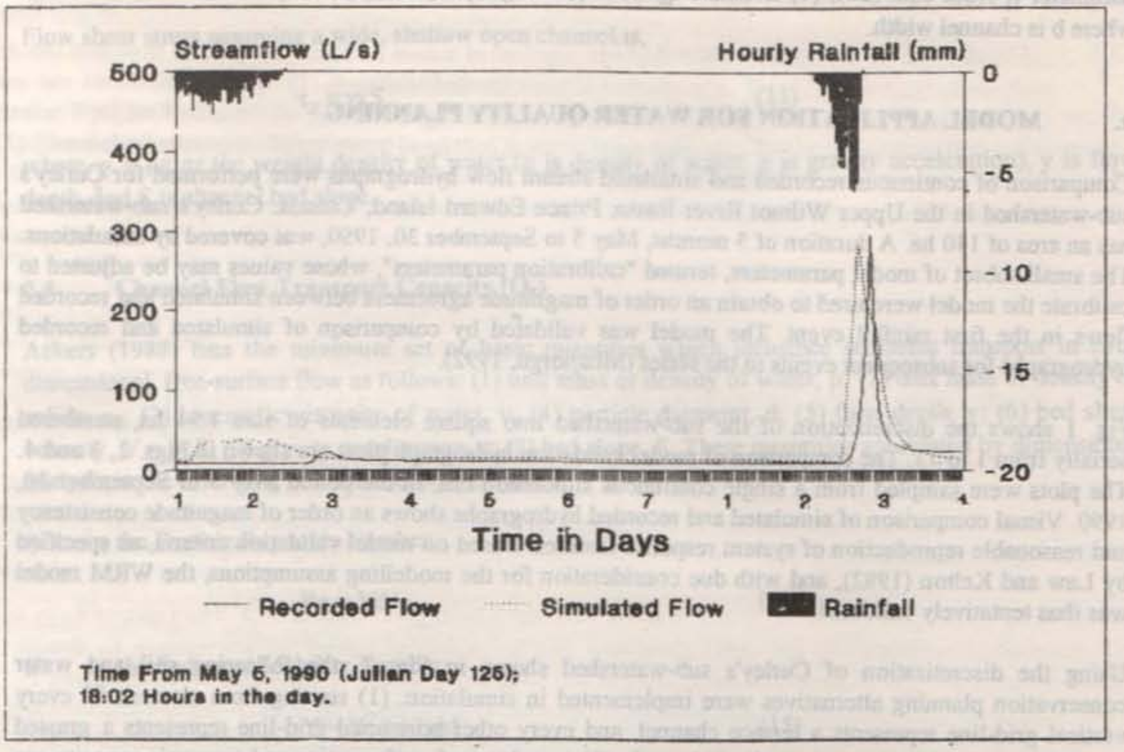

Fig. 2 Simulated and recorded hydrographs for Curley's sub-watershed (1)

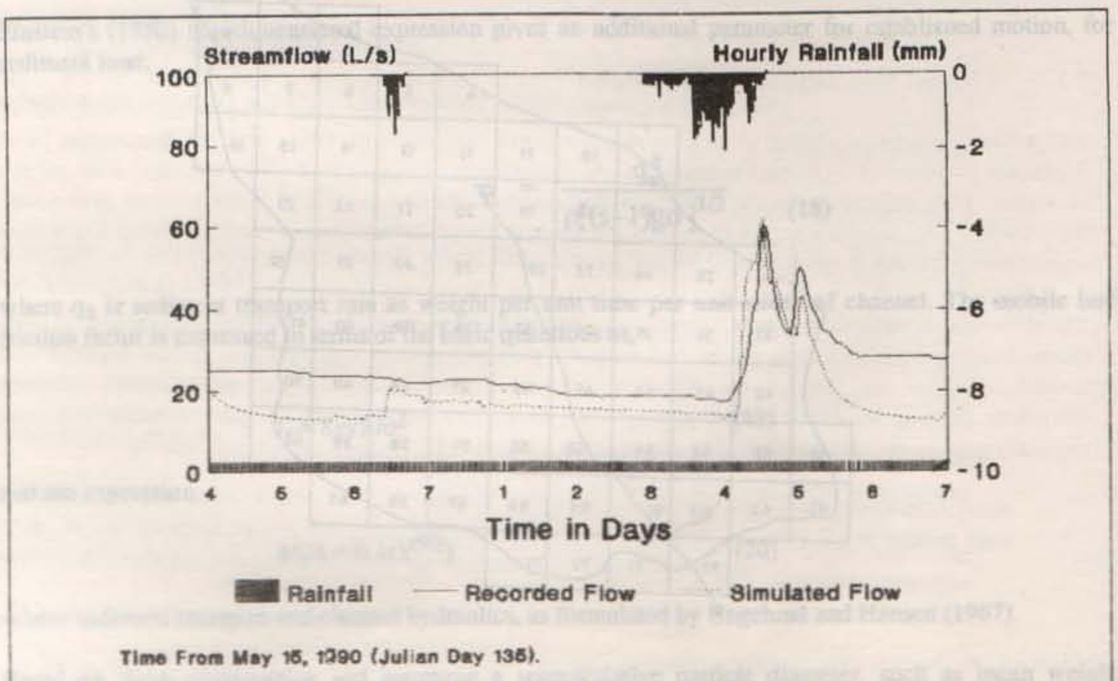

Fig. 3 Simulated and recorded hydrographs for Curley's sub-watershed (1)

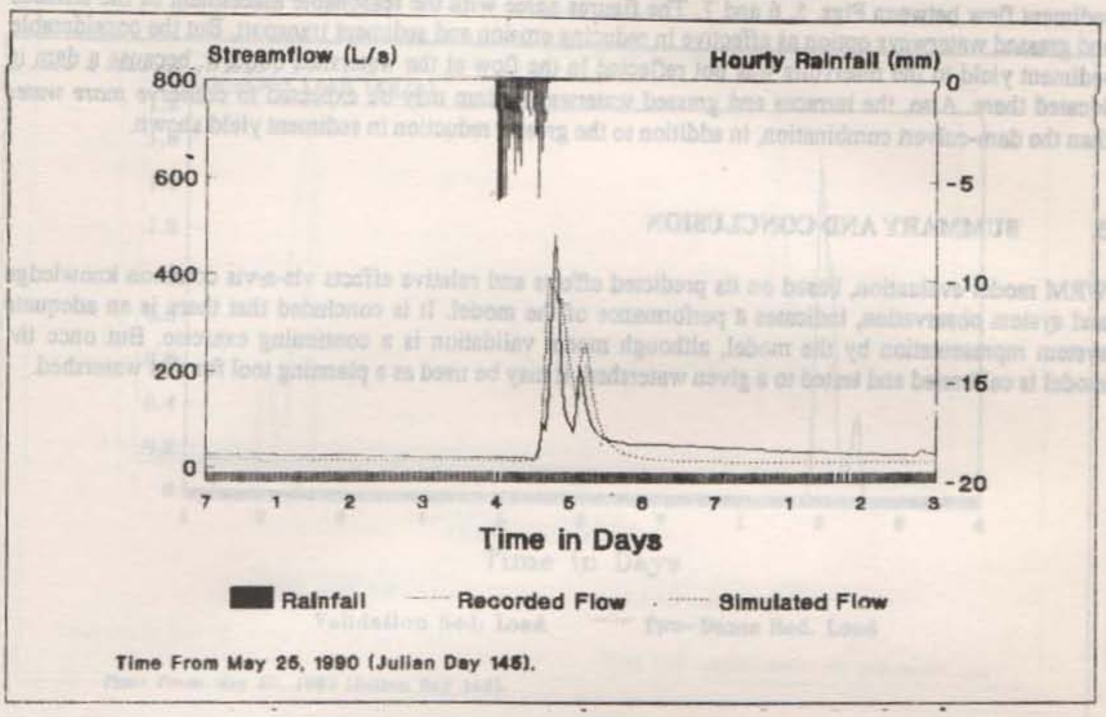

Fig. 4 Simulated and recorded hydrographs for Curley's sub-watershed (1)

In the simulation of the three scenarios, although the structures were hypothetically imposed on the system, the physical characteristics of the watershed (as inputed for model validation), and the assumptions in system representation, remain the same.

4. RESULTS AND DISCUSSION

Fig. 5, 6 and 7 illustrate the effects, with respect to stream sediment load, of the terraces and grassed waterways system, the 2-dams alternative, and the dam-culvert scenario, respectively. Similarly, Figs. 8, 9 and 10 illustrate their respective effects on stream sediment concentration. These model results represent only the specified output in model operation. WRM model is generic and capable of distributed output in space, time and variable.

Note in Figs. 6 and 9 that the plot of the two-dam sediment load (or concentration) coincides with the time axis, being zero in either case. Also, Figs. 5, 6 and 7 present sediment load as the rate of movement of soil material in the stream flow, without regard to the flow discharge. However, Figs. 8, 9 and 10 present sediment concentration which relates streamflow discharge to its sediment load, indicating the level of sediment pollution of the stream.

Figs. 5 and 8 show a reduction in erosion and sediment transport rate of the order of 50%, by the terraces and grassed waterways system. On the other hand, Figs. 6 and 9 show the effect of the two reservoirs, created by a dam at a remote upstream location and another dam at the watershed outlet, as zero sediment outflow. This is because the two-dams model tends to trap all the sediment. The model assumes total deposition in a reservoir, although considerable erosion and sediment transport may occur between the two dams. In Figs. 7 and 10 are shown the effect of a remotely located dam and a culvert near the watershed outlet. There is only a slight reduction in sediment outflow by the structural effect, which confirms that considerable erosion and sediment transport occurred below the remotely located dam. This was little affected by the culvert near the watershed outlet.

A somewhat more complex comparison may be drawn accross the results, by comparing the reduction in sediment flow between Figs. 5, 6 and 7. The figures agree with the reasonable assessment of the terraces and grassed waterways option as effective in reducing erosion and sediment transport. But the considerable sediment yield to the reservoirs was not reflected in the flow at the watershed outflow, because a dam is located there. Also, the terraces and grassed waterway system may be expected to conserve more water than the dam-culvert combination, in addition to the greater reduction in sediment yield shown.

5. SUMMARY AND CONCLUSION

WRM model evaluation, based on its predicted effects and relative effects vis-a-vis common knowledge and system observation, indicates a performance of the model. It is concluded that there is an adequate system representation by the model, although model validation is a continuing exercise. But once the model is calibrated and tested to a given watershed, it may be used as a planning tool for that watershed.

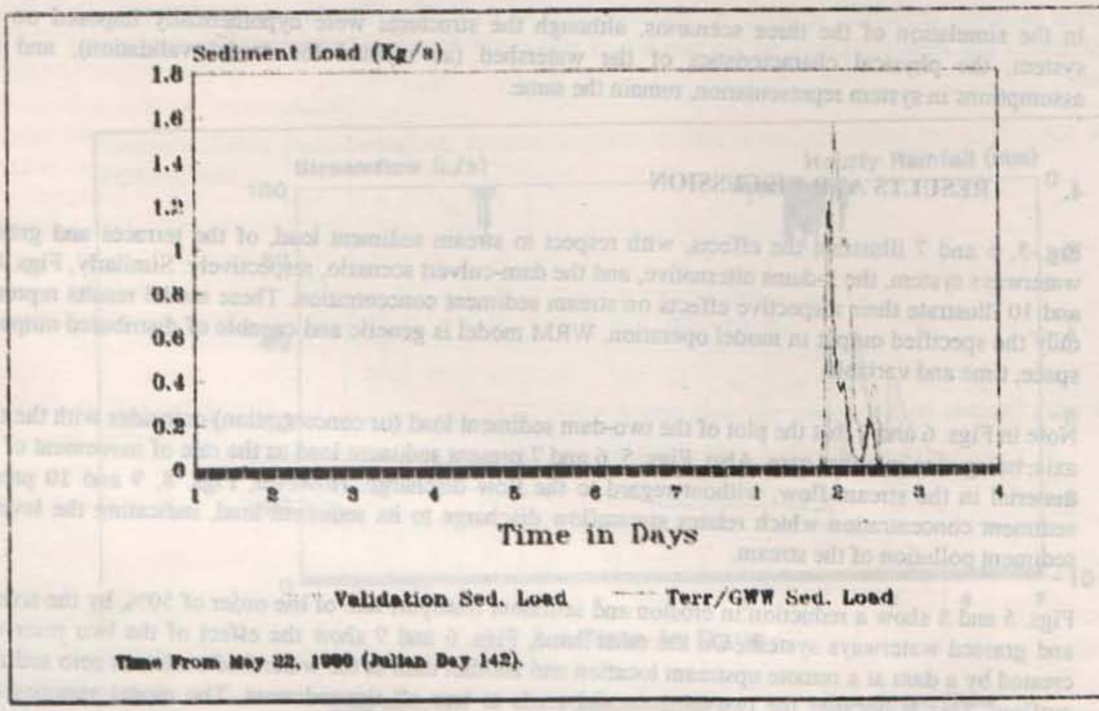

Fig. 5 Effect of a terraces/grass-waterway system on stream sediment load, Curley's sub-watershed.

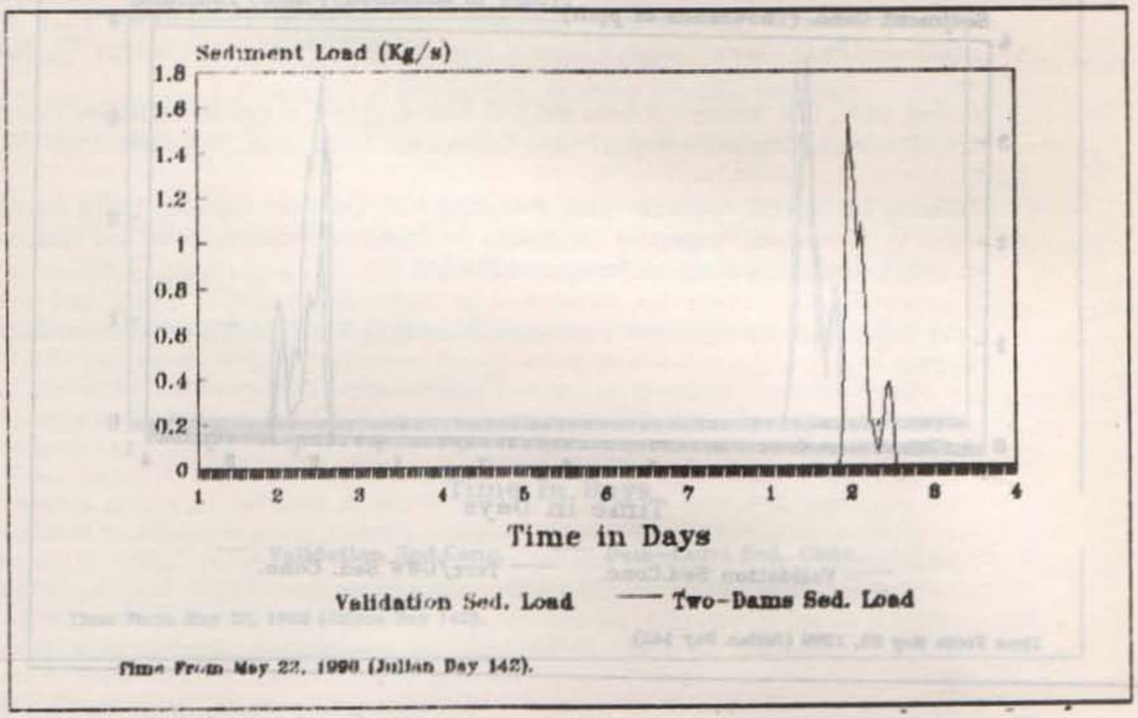

Fig. 6 Effect of two dams on stream sediment load, Curley's sub-watershed.

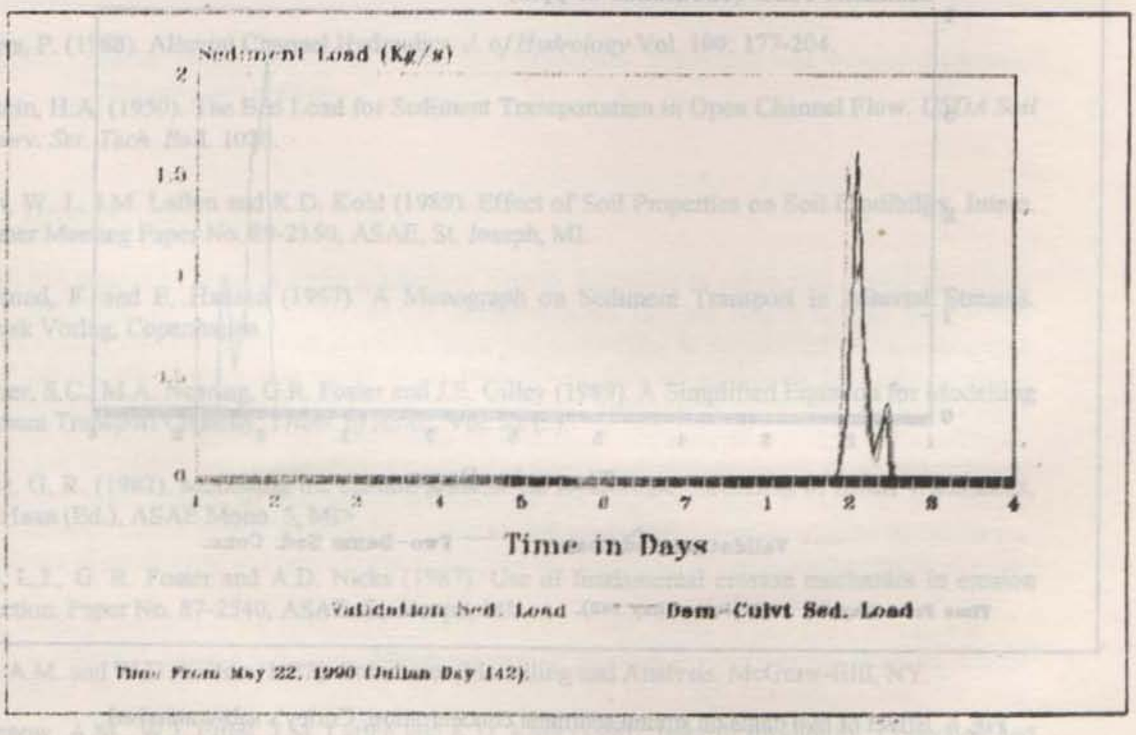

Fig. 7 Effect of a dam and culvert on stream sediment load, Curley's sub-watershed.

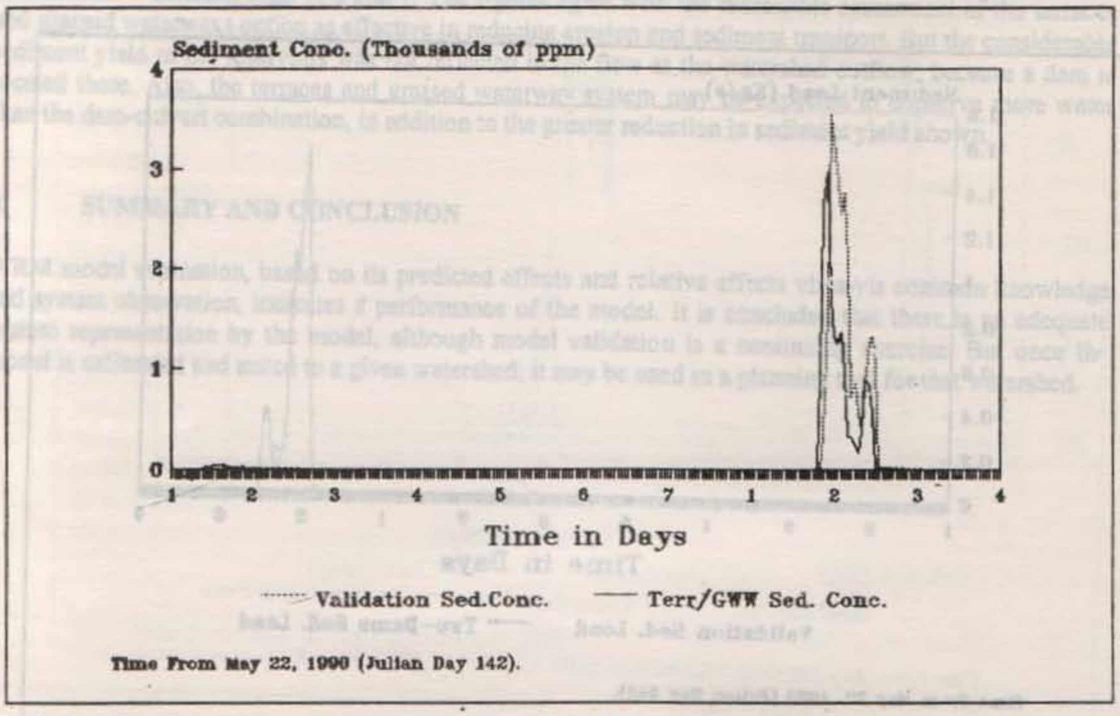

Fig. 8 Effect of terraces/grass-waterways system on stream sediment concentration, Curley's sub-watershed.

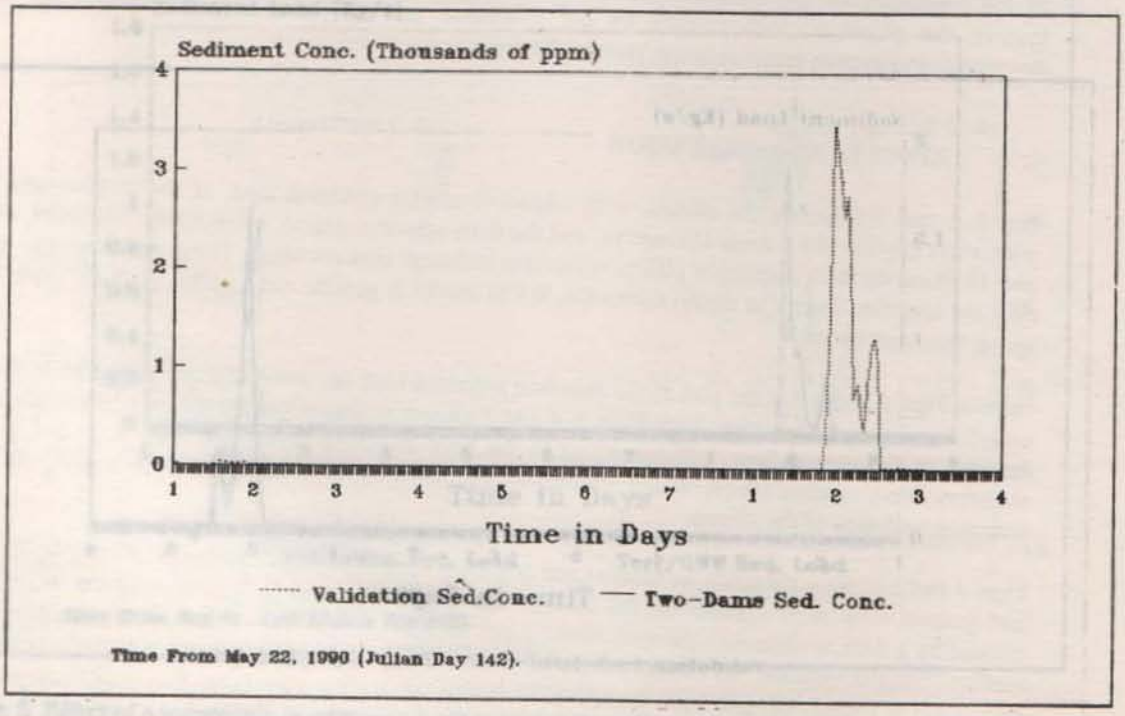

Fig. 6 Effect of two dams on stream sediment concentration, Curley's sub-watershed.

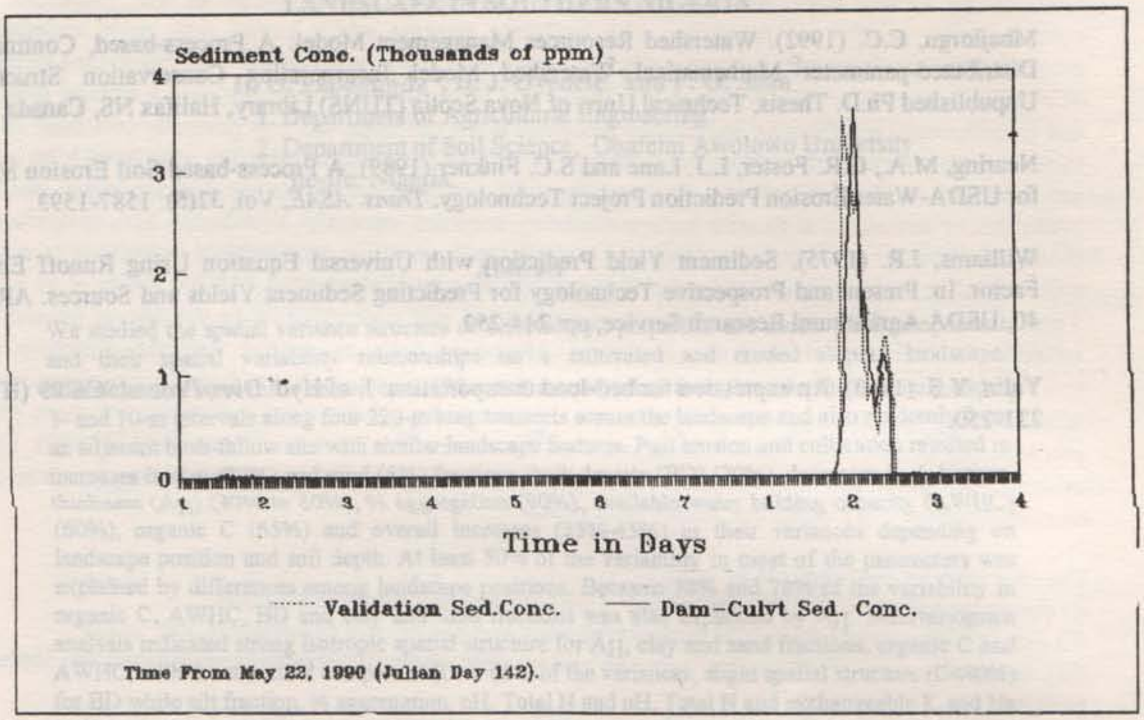

Fig. 10 Effect of a dam and culvert on stream sediment concentration, Curley's sub-watershed.

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SPATIAL VARIABILITY OF MAIZE YIELD AND SOIL PROPERTIES ON AN ERODED LANDSCAPE IN SOUTHERN NIGERIA

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Abstract

We studied the spatial variance structure of selected soil properties and maize yield components and their spatial variability relationships on a cultivated and eroded sloping landscape. Measurements were made on soil cores (76-mm diameter) taken from three depths randomly and at 1- and 10-m intervals along four 220-m long transects across the landscape and also randomly from an adjacent bush-fallow site with similar landscape features. Past erosion and cultivation resulted in increases in clay (20%) and sand (5%) fractions, bulk density (BD) (20%), decreases in A-horizon thickness (A_H) (30% to 60%), % aggregation (90%), available water holding capacity (AWHC) (60%), organic C (65%) and overall increases (25%-45%) in their variances depending on landscape position and soil depth. At least 50% of the variability in most of the parameters was explained by differences among landscape positions. Between 38% and 78% of the variability in organic C. AWHC, BD and clay and sand fractions was also explained by A_H. Semivariogram analysis indicated strong isotropic spatial structure for A_H, clay and sand fractions, organic C and AWHC, with the structural component (C) > 60% of the variances, slight spatial structure (C<40%) for BD while silt fraction, % aggregation, pH, Total N and pH, Total N and exchangeable K and Na had no spatial structure. Ranges of spatial dependence for soil properties were between 37m and 86m. Spatial variance structure was stronger in the 0- to 15-cm and 30- to 60-cm layers than in the 15- to 30-cm layer. Maize grain yield and stover dry weight were also isotropically spatially structured with longer ranges (59m to 65m) than most soil properties. Results indicated differences in the spatial variability patterns of yield among two landscape positions suggesting possible stationarity at the site. Cross-semi-variograms of yield and soil properties provided evidence of significant positive spatial correlation with A_H, organic C and AWHC and negative correlation with clay and sand fractions and BD and confirmed the predictability of maize yield-soil relationships on eroded landscape.

KEYWORDS: Spatial variability, Maize yield, Soil properties, Cultivated and eroded landscape, Semivariogram analysis.

1. INTRODUCTION

Accelerated soil erosion by water is evere in southern Nigeria. Estimates of substantial annual soil losses (Wilkinson, 1975; Lal, 1976; Aina, 1989) and the characteristically thin and fragile topsoils suggest that erosion rates exceed maximum soil-loss tolerance limits and detrimental to the productivity and sustained agricultural use of soils in the region where slopes from 5% to 10% are commonly bared for intensive farming. Relatively few studies have related soil erosion to soil productivity in the region. Most studies have examined erosion-soil productivity relationship by artificial desurfacing of soil (Lal, 1976; Mbagwu *et al.*, 1984) and by greenhouse comparison of topsoil and subsoil productivity levels (Aina and Egolum, 1980). However, such studies, as extensively reviewed by Stocking and Peake (1985), do not always reflect the effects of natural topsoil removal by erosion on soil productivity. Precise information about the interdependence of erosion and soil productivity is essential for proper soil management to control erosion.

Elsewhere, some researchers (Frye *et al.*, 1982; Mermut *et al.*, 1983; Stone *et al.*, 1985; Kreznor *et al.*, 1989) have investigated the effects of cummulative amounts of previous erosion on crop yields on natural landscape which facilitated the evaluation of the interactions of landscape features on soil and crop responses. Several of the studies have demonstrated significant differences in erosion-crop yield relationships among slope positions and have attributed such relationships to soil properties. The relationships among slope positions and have attributed such relationships to soil properties. The correlation of specific soil properties with landscape position which varied with study included the properties of organic matter, A-horizon thickness, available water, and particle size distribution (Hanna *et al.*, 1982; Stone *et al.*, 1985; Miller *et al.*, 1988). Soil properties vary naturally over a sloping landscape due to differential soil forming and erosion processes along the slope and it is generally conceded that the variation is not necessarily random but systemic. In view of the greater variability associated with erosion processes and landscapes and the close relationships between soil properties and landscape positions, evaluation of associated soils with known reliability becomes especially significant. This contention has prompted a number of investigators to adopt more spatially-sensitive geostatistical techniques to evaluate soil variability across natural landscape. Extensive studies by Nielsen *et al.* (1973), Vieira *et al.* (1981), Vauclin *et al.* (1983) and many others have accelerated our understanding in the use of geostatistical methods in soil spatial analysis. Statistical properties such as spatial variance structure using semivariograms or auto-correlograms, linear prediction models such as Kriging or autoregressive equations and spatial correlation structures are determined by geostatistical techniques for more precise predictability of soil and biomass parameters than the conventional statistics (Samra *et al.*, 1989). Spatial analysis of variation of erosion-related soil properties and crop yields can help identify cause-effect relationships between erosion and related crop yields.

The objectives of this study are to

(i) determine soil properties that are related to past erosion on a sloping landscape,

(ii) describe the spatial structure of the soil properties and maize yield components, and

(iii) assess the spatial relationship between maize yield and soil properties as affected by landscape position.

2. MATERIALS AND METHODS

2.1 The Study Area

The experimental area is located at the Obafemi Awolowo University (Nigeria) Teaching and Research Farm (4°30 E, 7°30 N). The area is characterized by a humid tropical climate with a bi-modally distributed average annual rainfall of 1225-mm and average annual temperature range from a minimum of 293.5K to a maximum of 305.0K. It is a rolling topography of 1 to 10% slope and underlain by metamorphic rocks (mainly banded gneisses) belonging to the Pre-Cambrian Crystalline Basement Complex. The research sites consisted of a field that had been cultivated to arables under rainfed conditions for 10 years with erosion history and no fertilizer inputs, and an adjacent land under long-term (>30 year) forest fallow.

2.2 Field Methods

A landscape of approximately 250-m length across four landscape positions: summit, shoulder, backslope and footslope was selected at the eroded site using standard surveying techniques and Ruhe's (1960) slope classification scheme. Three of these (summit, shoulder, and backslope) were located at the fallow site with slope gradient, slope shape, soils and landscape position similar to those at the eroded site to provide pre-cultural erosion information for the eroded site. Each landscape position was segmented into 30- x 30-m units and four auger (7.6-cm diameter) samples within a radius of 1 m were collected at 10 random locations and bulked for the depths of 0 to 15, 15 to 30 and 30 to 60 cm. The thickness of the A-horizon (A_H) (at the fallow site), the depth to a reference horizon (A_R), slope features and moisture colour of horizons were determined at each location. The reference horizon was selected for each landscape position at both sites to determine A_H for the eroded site from the differences in A_R between the corresponding positions at the fallow (original depth) and eroded sites. The reference horizons were characterized by a gravelly sandy clay loam and matrix 5YR 4/5 at the summit and shoulder, very gravelly loamy sand 5 YR 4/4 at the backslope and gravelly sandy clay loam 5 YR 4/6 at the footslope with depths of occurrence varying depending on landscape position. A summary of landscape characteristics is presented in Table 1.

TABLE 1

Landscape characteristics at the bush fallow and eroded sites

Landscape position	Fallow summit	Fallow shoulder	Fallow backslope	Eroded summit	Eroded shoulder	Eroded backslope	Eroded footslope
Soil series	Oxic Paleustalf	Oxic Paleustalf	Oxic Paleustalf	Oxic Paleustalf	Oxic Paleustalf	Oxic Paleustalf	Oxic Haplustalf
Slope gradient, %		3-5	8	2	3-5	10	1
Length, m	40	38	98	45	35	120	52
Shape	convex	convex	linear	convex	convex	linear	linear
A_R, cm							
mean	44.6	45.2	48.6	40.0	38.8	38.7	41.8
range	38.0-57.2	35.1-56.1	36.5-60.2	33.252.7	30.7-49.8	26.1-50.4	31.8-57.3
CV %	11.6	16.2	14.1	16.7	18.9	19.3	22.6
A_H, cm							
mean	16.9	15.9	17.6	12.3	9.5	7.7	14.4
range	15.4-20.8	14.4-19.2	13.6-22.7	10.4-15.8	7.0-12.6	5.2-12.4	10.2-19.7
CV %	13.8	18.6	17.4	14.6	16.7	24.8	18.0

Four 220-m transects, 40-m between adjacent transects, were constructed at the eroded site parallel to the hillslope gradient with 10-m sampling intervals. A soil core, 76-mm diameter and 60-mm long was taken at two close (<50 cm) locations at each observation point along the transect. Additional samplings were made at 1-m intervals on a 100-m segment of one of the transects. Cores were sliced and bulked according to horizons after determination of the A_H, thickness of Ap horizon and A_R.

Maize (*Zea mays*), planted at a spacing of 100- by 25-cm was grown during March to August 1986 with no tillage rainfed conditions and no fertilizer inputs. Maize grain yield (adjusted to 15.5% moisture content) and stover dry weight were determined over 1- by 1-m area (cell) at each sampling point with the cell centroid coinciding with the sample location. Yields were also determined at 1-m intervals along four crop rows traversing all landscape positions and for the entire site by landscape position.

2.3 Laboratory Analyses

Air-dried soil samples were sieved to <2-mm and analysed for the following characteristics: particle size distribution by the hydrometer method (Day, 1965), bulk density on core samples, available water holding capacity (AWHC) calculated as the water released between -33 and -1500 kPa and determined using pressure plate extraction (Klute, 1976), percentage aggregation (Kemper, 1965), pH with a glass electrode in a 1:1 soil/water suspension, Bray-P, Total N and organic carbon by the Walkley-Black method (Allison, Soil heterogeneity at the eroded site was partly explained by the differences between landscape positions which were significant at the 5% level. Sand and clay fractions and bulk density all decreased in the sequence: backslope > shoulder > summit > footslope while AWHC, A_H and organic C and several chemical properties had the reverse trend, although the differences in percent aggregation, pH, Total N, K and Na were not significant. Analysis of variance showed that at least three of the landscape positions (summit, backslope and footslope) were different at the 5% significant level for the measured soil properties except silt, pH, Total N, aggregation and exchangeable K. More than 50% of the variance in A_H, clay fraction, organic C and AWHC and <40% for sand, BD and exchangeable Ca and Mg was explained by the differences between landscape positions (Table 3). The variance within each landscape position was always smaller than that between landscape positions and had the sequence: backslope>footslope>shoulder>summit with mean CV values of 28%, 24%, 23% and 19% respectively. More than 20% of the variability associated with clay and sand fractions, organic C and AWHC was explained by the differences between soil depths within landscape position. Variance between soil horizons was highest on the footslope compared to other positions apparently due to layering of materials of varying grades washed in from upper slope positions.

One property that is commonly associated with erosion isA_H. A_H at the eroded site was reduced as a consequence of cultivation and erosion from about 26% on the summit, and 40% on the shoulder to 56% on the backslope. Regression of soil properties on A_H for the whole landscape showed that decreases in A_H explained 35% and 78% of the increases in sand and clay fractions, respectively. This apparently was due to the gradual incorporation of the more clayey B-horizon subsoil materials into the surface soil by cultivation as the profile was thinned and fine soil materials preferentially removed by past erosion. Approximately 44% of the increase in BD, 62% and 58% of the decreases, respectively, in organic C and AWHC were explained by decreases in A_H.

TABLE 3

Sources and amount of variation of selected properties within and between landscape

position and depths	Soil Property					
Source of variation	A_H	Clay	Sand	AWHC	BD	Org. C
Landscape position	60	57	39	52	31	51
Within landscape	15	8	18	10	7	5
Soil depth	0	25	21	21	29	35
Replication	10	5	12	7	15	2
Error	15	5	10	10	18	7
Total (239 df)	100	100	100	100	100	100

3.2 Spatial Variation of Soil and Crop Parameters

Transect data of soil and crop parameters showed considerable variation with distance along the transect such as exemplified by Fig. 1. Results showed a slight increase in AWHC, A_H and organic C at one end of transect while the distribution of clay and sand fractions and BD indicated a reverse trend. Such variations may be due in part to surface soil redistribution by past erosion. In contrast to the distribution in the surface, results for deeper layers especially the 15-30 cm depth exhibited no obvious pattern. Larger variations at the 30-60cm depth reflected differences in parent material across the landscape. Results (for brevity, values are not included) also indicated a lack of extensive variation along the transect for the silt fraction, pH, aggregation and exchangeable Na.

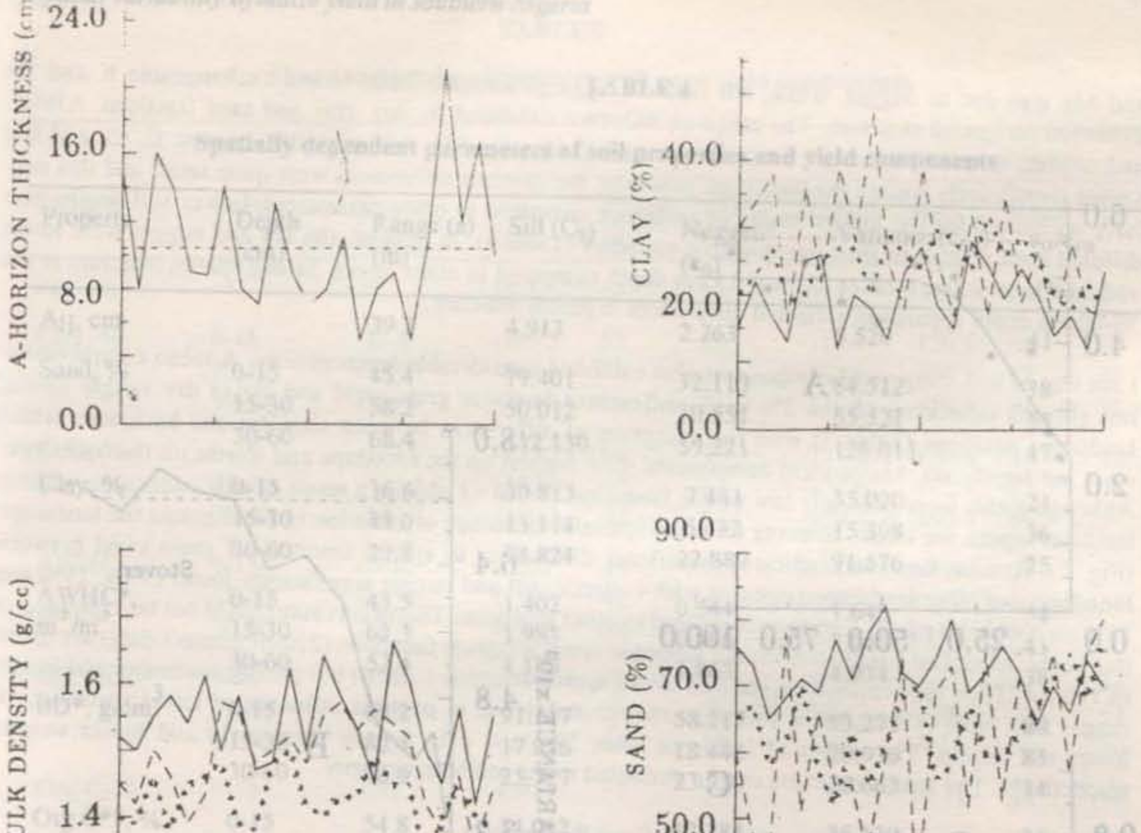

FIG. 1. Variation of soil properties with distance along the transect for the 0- to 15-cm (—), 15- to 30-cm (• • •) and 30- to 60-cm (- - - -) depths

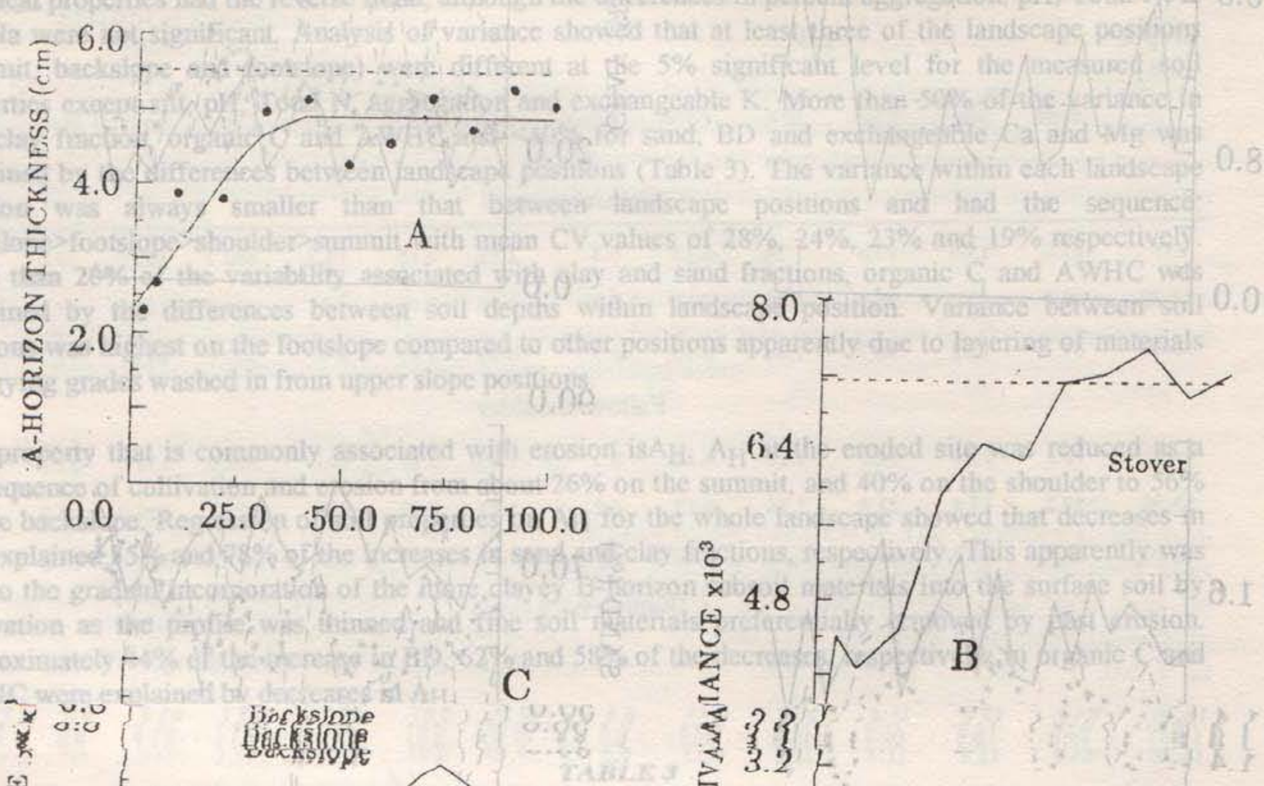

FIG. 2. Semivariograms for (A) A-horizon thickness and (B) yield components from 220-m transect and (C) grain yield from landscape segment transects

TABLE 4

Spatially dependent parameters of soil properties and yield components

Property	Depth (cm)	Range (a) (m)	Sill (C_S)	Nugget (c_0)	Variance (c_{va})	c_0/c_{va} (%)
A_H, cm		39.2	4.913	2.263	5.520	41
Sand, %	0-15	45.4	79.401	32.110	84.512	38
	15-30	58.2	50.012	30.551	55.521	55
	30-60	68.4	112.130	59.221	126.013	47
Clay, %	0-15	36.6	30.813	7.441	35.020	21
	15-30	49.0	13.114	5.432	15.398	36
	30-60	29.8	78.824	22.889	91.576	25
AWHC*, m^3/m^3	0-15	43.5	1.402	0.544	1.643	34
	15-30	62.3	1.983	0.996	2.246	43
	30-60	52.4	4.175	1.863	4.934	38
BD*, g/cm^3	0-15	68.2	91.117	58.217	93.271	88
	15-30	82.4	17.826	18.442	20.936	83
	30-60	86.9	25.727	23.750	28.663	34
Org C**, %	0-15	54.8	34.012	12.284	36.130	34
	15-30	-	2.744	2.706	2.824	98
	30-60	-	0.112	0.109	0.114	100
Exchangeable, µg/g						
Ca	0-15	71.8	866.2	547.1	1056.3	52
	15-30	85.2	677.3	586.5	826.0	71
	30-60	69.4	1129.3	571.0	1268.9	45
Mg	0-15	85.7	53.326	41.621	68.315	61
	15-30	78.2	75.613	53.432	82.221	65
	30-60	85.4	74.726	62.610	86.935	72
Grain yield, g/cm^2		58.6	1218.4	288.0	1107.6	26
Stover dry wt, g/cm^2		65.4	7651.6	3219.6	7154.7	45

$*x10^{-4}$, $**x10^{-3}$ for sill, nugget and variance

Analysis of spatial dependence using semivariograms indicated that variation of soil properties and crop components was isotropic and the spherical model, weighted for the number of pairs in each lag, provided good estimate of the isotropic semivariogram parameters as presented in Table 4. The sill values of the estimated semivariogram were generally similar to the sample variance, indicating a general absence of trends across the site and that the spherical model adequately represents the behaviour of the semivariograms. Burrough *et al.* (1983) observed that in most soils where several factors of soil formation have operated at different intensities, such as erosion scenario as in this case, the nugget variance would be sizeable. In our study, the structural component was, however, predominant. Results showed strong spatial structure for A_H (Fig. 2), clay and sand fractions, AWHC and organic C with the structural component explaining 40 to 80% of observed variability in these properties. More than half the variance for BD, Ca and Mg was due to nugget, while, silt fraction, aggregation, pH, Total N and exchangeable K and Na exhibited no spatial structure. The range of influence exhibited by A_H, clay and sand fractions, AWHC and organic C were 36.6 to 54.8m and increased to 68m for BD. Although BD, organic C, Ca and Mg varied significantly among the landscape positions, the absolute differences were quite small and this may have accounted for the longer ranges of influence compared to other parameters. Lower soil depths also differed with respect to their interpretable variation (Table 4). In general, the sill and nugget were lower and spatial structure weaker in the 0-15 cm depth compared to other layers. Strong spatial structure at the 30-60 cm depth apparently reflected differences in parent material.

Like that of soil, crop yield components also exhibited considerable heterogeneity. A mean comparison t-test showed significant (at the 5% level) differences in maize grain yield and stover dry weight among landscape positions (Table 5) with the exception of differences between shoulder and backslope which were not significant. Maize yield components were highest on the footslope and lowest on the backslope. Although yields were generally low on the landscape (mean <1 t/ha) as a result of past cultivation without fertilizer inputs, the trends however reflected spatial dependence of variation in yield across the landscape (Fig. 2). Results, however, indicated significant differences in spatial structure of grain yield between footslope and other landscape positions with variance, sill and nugget significantly lower (33%, 29% and 25% respectively) on the footslope compared to other positions. This observation could not be explained in this study. Modelled parameters for the isotropic semivariogram functions (220-m transect data) are given in Table 4. Their semivariograms showed strong spatial structure (>55%) but greater continuity and longer ranges than most of the surface soil properties probably due to possible influence of lower variability of lower soil depths. The ranges of influence were 58m and 65m for the grain yield and stover weight, respectively. The spatial structure can be attributed to the soil heterogeneity.

3.3 Cross-semivariogram of Soil and Crop Parameters

Results of interrelationships of selected soil parameters and crop yield components modelled through cross-semivariogram functions indicated that AWHC, A_H and organic C were spatially positively correlated with grain yield and stover dry weight, whereas, BD and sand and clay fractions affected crop yield components adversely (Table 6). Cross variability was in the sequence: % clay > AWHC > Organic C > A_H > % sand > BD with the structural component of the cross-semivariograms varying from 48% to 74% of the variances. Cross-variability of yield components with soil depth was relatively higher in the surface soil and lower in the 15 to 30-cm layer compared to the 30- to 60-cm depth. These results showed significant soil horizon (up to 60-cm depth) influence to varying degrees on maize yield components. The cross-variogram was found to be less than the square root of the respective variances for the measured soil variables indicating that the heterogeneity in maize yield components was a reflection of soil variation, thus confirming the predictability of maize yield-soil relationships. These results were consistent with results of multiple regression of crop parameters on soil properties which indicated that A_H, AWHC and organic C accounted for 48% and 43% of the variances in grain yields and stover dry weight, respectively.

TABLE 5

Mean[1] and coefficient of variation (CV) comparisons of yield components across landscape positions

Landscape position	Grain yield g/m^2	CV, %	Stover dry wt, g/m^2	CV, %
Summit	102.3a	16.4	278.6a	13.4
Shoulder	78.5b	18.0	268.5ab	16.3
Backslope	65.2b	19.2	263.8b	15.8
Footslope	132.2c	13.3	324.1e	10.1

[1]Means within a column followed by the same letter are not significantly different (P = 0.05).

TABLE 6

Cross-variogram parameters with corn yield components

		Grain yield, g/cm^2				Stover dry wt, g/m^2			
Property	Depth	Nugget (C_o)	Sill (C_s)	Range (a)	C_o/C_s	Nugget	Sill	Rang e	C_oC_s
A_H, cm		28.3	69.1	66	41	83.3	189.3	78	44
Clay, %	0-15	-28.4	-109.3	57	26	-113.4	-420.1	68	27
	15-30	-37.9	-105.2	48	36	-185.0	-430.2	72	43
	30-60	-146.8	-310.0	65	71	-530.6	-758.0	84	70
Sand, %	0-15	-138.7	-295.2	64	47	-277.1	-659.8	58	42
	15-30	-122.1	-197.0	67	62	-430.9	-582.4	67	74
	30-60	-151.2	-360.1	52	42	-329.4	-890.3	59	37
AWHC, m^3/m^3	0-15	0.086	0.262	49	33	0.348	0.892	69	[illegible]
	15-30	0.156	0.390	42	40	0.406	0.922	64	[illegible]
	30-60	0.498	0.682	58	73	1.233	1.601	81	[illegible]
BD, g/cm^3	0-15	-1.54	-2.96	68	52	-2.52	-5.72	45	44
	15-30	-1.07	-1.41	78	76	-2.36	-3.68	58	64
	30-60	-0.81	-1.66	65	49	-1.66	-3.32	53	50
Org C, %	0-15	1.91	4.90	52	39	5.83	14.21	48	41

4. CONCLUSIONS

Based on comparison with the uncultivated and uneroded bush-fallow site, we believe that erosion and cultivation over the 10 year period had resulted in 27% to 60% loss in the A-horizon and considerable changes in soil properties which were strongly associated with landscape positions across the eroded landscape. At least 50% of the variations in soil properties was explained by differences in landscape positions. Results also showed strong dependence of certain properties on A_H, which explained about 40% of the variability in yield and at least 50% of the variabilities in clay fraction, AWHC and organic C. This suggests the use of A_H as an indicator of past erosion.

Maize yield components were spatially correlated positively with A_H, organic C and AWHC and negatively with BD and clay and sand fractions. These results which were consistent with results of multiple regression of yield components on soil properties are indicative of predictability of maize yield-soil relationships. Differences in the spatial structure of yield observed among two landscape positions may reflect the patterns of soil variance which could not be investigated in this study but may affect the non-stationarity assumption made here in the spatial analysis.

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EVALUATING SURFACE IRRIGATION SYSTEM UNDER HIGHWATERTABLE CONDITIONS

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Abstract

Three methods of surface irrigation: border, furrow and check basin were evaluated at the Kadawa Irrigation Project which has been facing waterlogging and salinity problems due to increasing rise in the water table levels (Nwa, 1980). The experiments consisted of a split block design replicated three times in which the treatments were irrigation intervals of one week, two weeks and three weeks.

It is found that the best method is the check basin at 2-week irrigation interval. This gave an acceptable water table depth for wheat growth and also a high grain yield. The furrow irrigation method at 1-week interval can also be used. The border method did not perform well under all the treatments. The general practice whereby farmers irrigate at 1-week intervals in the Kadawa Irrigation Project irrespective of the method of irrigation should be discouraged. The prevailing waterlogging problems in the area can mainly be attributed to too frequent irrigations and excessive water applications. The estimated contribution of soil moisture by the groundwater table is found to be substantial in all the irrigation treatments. Thus, a consideration for the moisture contribution from the groundwater table should be included in scheduling irrigation in the project area.

KEYWORDS: Surface irrigation, Waterlogging, Salinity, Watertable

1. INTRODUCTION

High water table conditions very often develop as a result of sub-optimal irrigation practices which may arise from lack of drainage facilities, seepage losses from canals and excessive water application to the fields. High water table, waterlogging and salinity are already problems which have arisen in a number of irrigation projects due to the rapid expansion in Nigerian irrigation projects (Nwa, 1980).

The high water table problems can be solved ultimately by drainage, but the high cost of drainage materials makes this option difficult to implement. The practicable option, for the time being, is to embark on programmes that will lead to improved water management on the irrigated fields. A system evaluation of the existing irrigation projects is therefore desirable at the present stage of development. Such an evaluation would quantify the effectiveness of existing practices, and show what improvements can be made in operating the systems.

This paper presents a study on the evaluation of border, furrow and basin irrigation methods under high water table conditions. The study was carried out during the 1986/87 irrigation season at the Kadawa Irrigation project.

2. MATERIALS AND METHODS

The experiment was conducted using a split block design replicated three times in a field sown with wheat. The main treatments were border, furrow and check basin irrigation methods and irrigation intervals of 1-week (T_1), 2-Week (T_2) and 3-Week (T_3) were the sub-treatments, and were imposed 14 days after planing. The following measurements were taken during the study: (1) water table depths at 1-week intervals (2) soil moisture content before and after each irrigation (3) advance and recession curves (4) amount of water applied (5) dry matter yield and (6) grain yield.

The measurements required for evaluating the adequacy of an irrigation system include: soil moisture deficiency; rate of advance and recession; rate of inflow; uniformity of water application; soil conditions; and the appropriateness of the irrigation practice. These factors are not independent as they interact and their net effects can be obtained by the analysis of the advance and recession curves, the water application and distribution efficiencies, the deep percolation and moisture contribution by groundwater and the water application depth (Merriam, 1980).

2.1 Irrigation Methods

The border strips were 4.0m in width and 90.0m long; the basins, 5.0m by 5.0m, based on the recommendations of Murty and Argawal (1970); and the furrows were spaced 0.75cm and of length 90.0m. 40-mm Diameter siphon tubes were calibrated and used to divert water from the field channels to the experimental plots. The siphon tubes were calibrated in order to determine the water inflow rates into the experimental plots.

The border strips were irrigated using an average inflow rate of 3.261/s/m for the 1-week, 2-week and 3-week intervals. For the furrow irrigation treatments, an average inflow rate of 0.6 l/s was introduced into each furrow. In the basin irrigation treatments, an average net irrigation water depth of 14, 24 and 30mm was applied for the 1-week, 2-week and 3-week intervals, respectively.

2.2 Advance and Recession Curves

The times of advance of the water front to marked points at a spacing of 15m apart along the border and furrow strips were determined. The inflow was cut off when the water advanced to the lower end of the border and furrow strips as practiced by the farmers and the times during which the water receded to the established points were also noted.

When the advance and recession curves are approximately parallel, the water distribution uniformity will be high, indicating that a proper stream size has been used. The recession curve obtained for any given strip is found to be approximately the same for all stream sizes (Merriam, 1980). In the design of border irrigation systems the inflow rate has to be adjusted until the advance and recession curves become approximately parallel, to ensure a high value of water distribution efficiency. Other factors that influence the shape of the advance and recession curves are: soil intake rate, shape and size of field and crop and soil roughness. Inadequate inflow rate for example, causes the curves to converge or diverge. Thus, border and furrow irrigation systems can be evaluated by observing whether or not the advance and recession curves are approximately parallel.

2.3 Soil Moisture Measurements

Soil moisture content measurements were done by the use of neutron meter (Troxler model). The meter was calibrated to obtain a suitable calibration curve for the area. Neutron count readings were taken at incremental depths of 150mm down to a point just above the water table, as determined from the piezometers installed for water table depth measurements. The neutron count readings were then converted to moisture content values by using the calibration curve determined for the area. The moisture content measurements were made just before and one day after each irrigation due to the light nature of the soil texture.

2.4 Water Application and Distribution Efficiencies

The water application and distribution efficiencies were calculated from the soil moisture measurement using Eqs. 1 and 2, given by (Isrealson and Hansen, 1962):

$$E_a = W_s/W_d \times 100 \qquad (1)$$

and

$$E_d = (1 - d/D) \times 100 \qquad (2)$$

where

E_a = water application efficiency (percent),
W_s = water stored in the plants' root zone (mm)
W_d = water delivered to the field (mm)
E_d = water distribution efficiency (percent)

D = average depth of water stored along the strip during irrigation (mm)
d = average numerical deviation from D (mm)

2.5 Estimate of Moisture Contribution from Groundwater

The amount of soil moisture contribution from the groundwater table was estimated using a water-budgeting method. The moisture added to the root zone is estimated from the moisture content before and after each irrigation using,

$$US = MC_2\ (i) - MC_1\ (i+1) \qquad (3)$$

where

US	= moisture added for one irrigation.
MC_2 (i)	= moisture content after i th irrigation.
MC_1 (i+1)	= moisture content before (i+1)th irrigation
i	= irrigation number

The moisture applied, US is then compared with the actual evapotranspiration, ET_a estimated from:

$$ET_a = K_c ET_o \qquad (4)$$

in which K_c is the crop coefficient and ET_o is the reference crop evapotranspiration, estimated from the procedure detailed by Doorenbos and Pruitt (1977), and Abdulmumin (1987). The mean 1-day values of K_c for wheat crop determined from lysimeter studies at Kadawa by Abdulmumin (1988) were used to solve Eq. 4. When the moisture applied is greater than ET_a, the excess becomes soil moisture storage and deep percolation loss and when less, there is a contribution from the groundwater table.

2.6 Crop Yield Measurements

Average above-ground dry matter yield was determined for each of the irrigation treatments at 2-week intervals throughout the irrigation period using a destructive method.

The total dry matter yield and grain yield were also obtained at the time of harvest.

3. RESULTS AND DISCUSSION

3.1 Advance and Recession Curves

Figures 1, 2, 3 and 4 give typical advance and recession curves for the study. The curves indicate that a uniform water application was achieved and the stream size was adequate, because they were approximately parallel. It was found that the advance and recession curves in Fig. 1 diverge at the upper end of the field when an inflow rate of 3.11/s/m was used, which indicates an over-irrigation of the upper end. Consequently, a higher inflow rate of 3.261/s/m was used in subsequent irrigations to provide a faster rate of advance and better water distribution uniformity for the border strips. The advance and recession curves for the 1- and 2-week furrow and border irrigation practices were also found to be satisfactory as indicated by the approximately parallel advance and recession curves in Figs. 3 and 4.

3.2 Soil Moisture Measurement

The soil moisture data is given in Table 1 for all the irrigation treatments. It is recognized that different amounts of water were applied in each of the irrigation methods. In the border and furrow methods, water in excess of that required by the soil rootzone was disposed off by surface runoff and deep percolation losses alone. Since the flow rates used are those estimated from the field on the basis of efficient irrigation

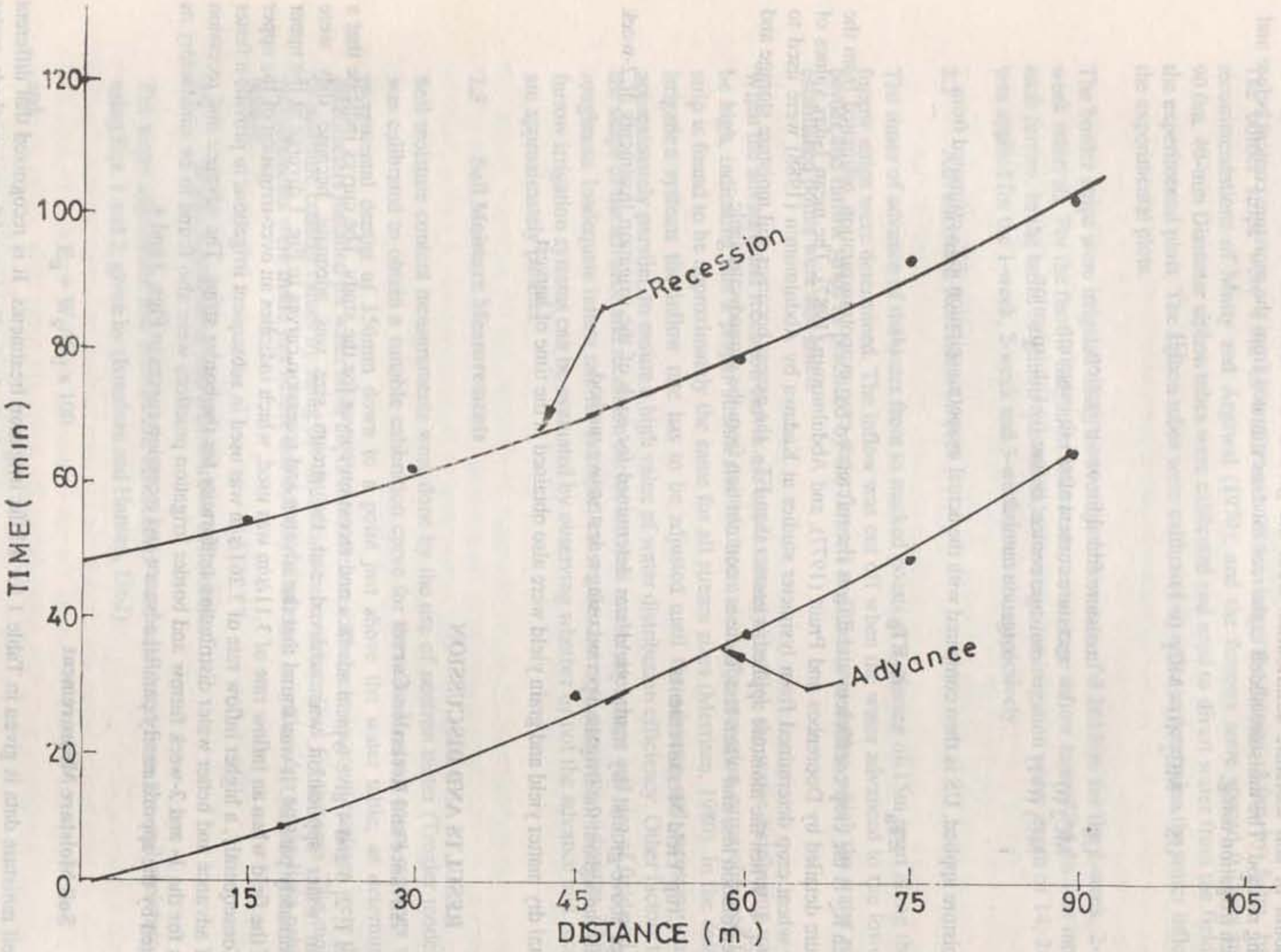

Fig. 1. **Advance and recession curve for border strip - 1-2A. 1-week irrigation interval. 15 DECEMBER 1986 ($q_c = 3 \cdot 1$ l/s/m, irrig. no 2).**

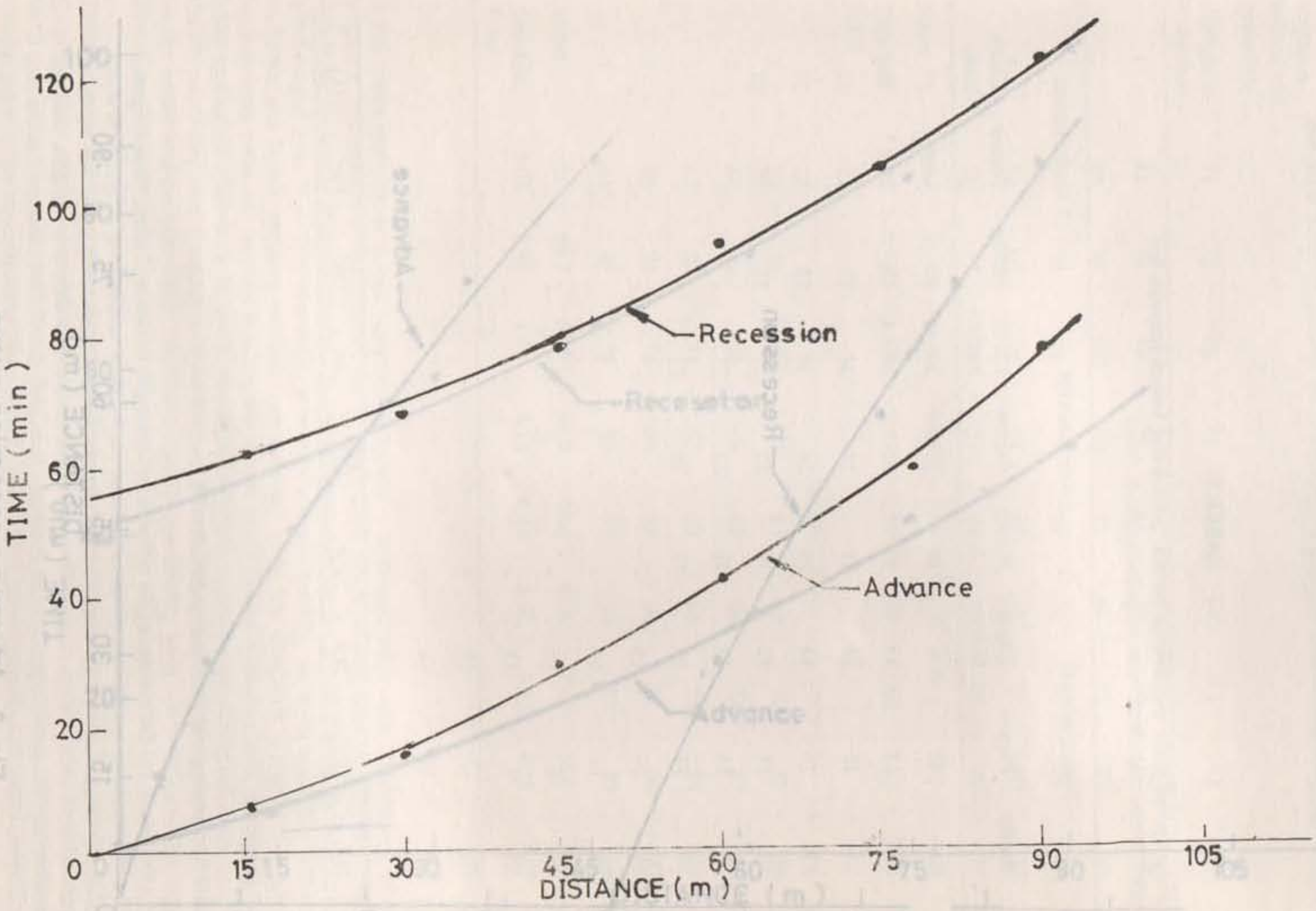

Fig. 2 Advance and recession curve for border strip B-1-2A. 1 week irrigation interval 29th January, 1987. ($q_* = 3 \cdot 26$ l/s/m , irrig. no 6) .

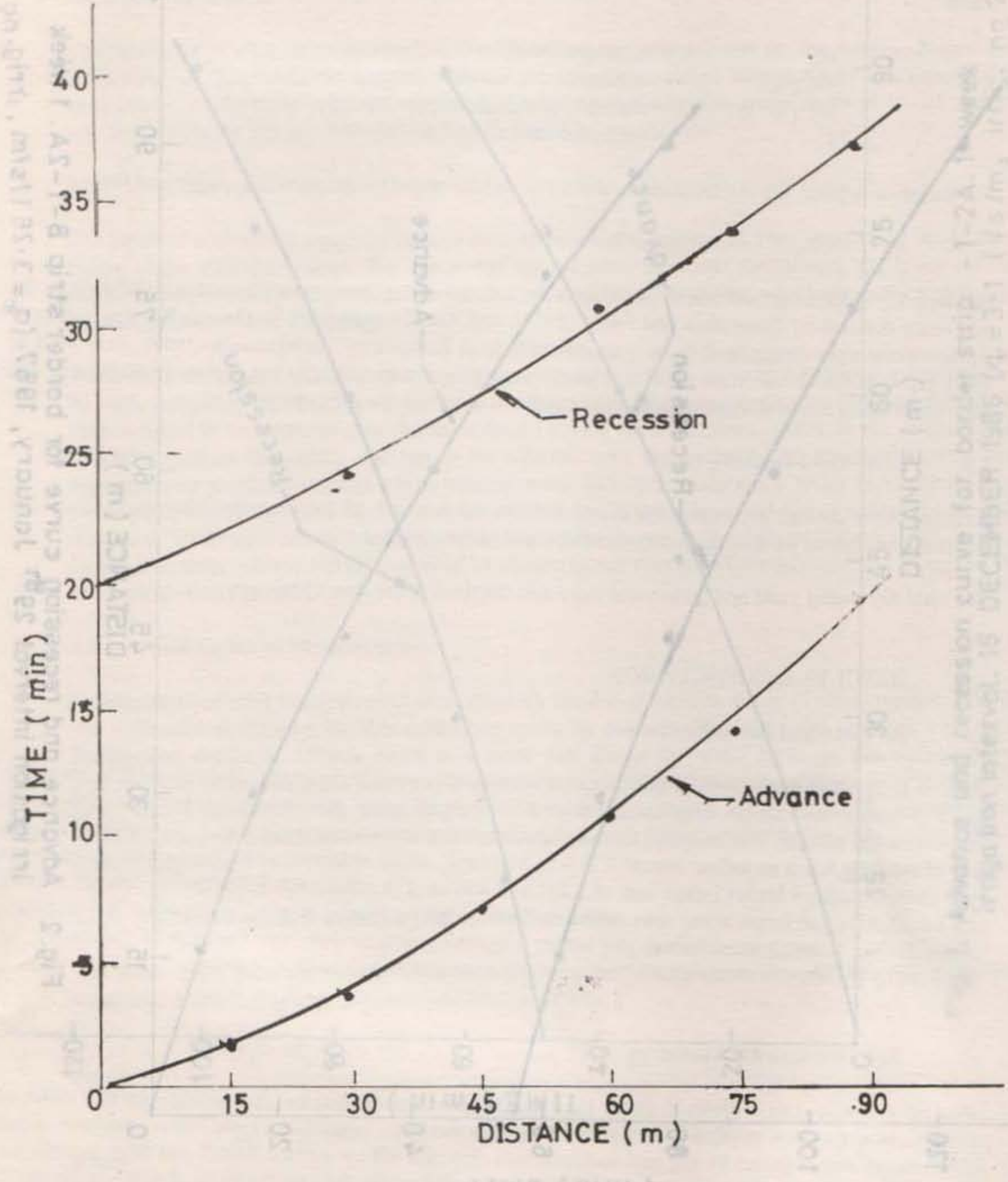

Fig. 3- Advance – recession curve
1– week furrow irrigation (Q = 0·6 l/s, irrig. no 5).

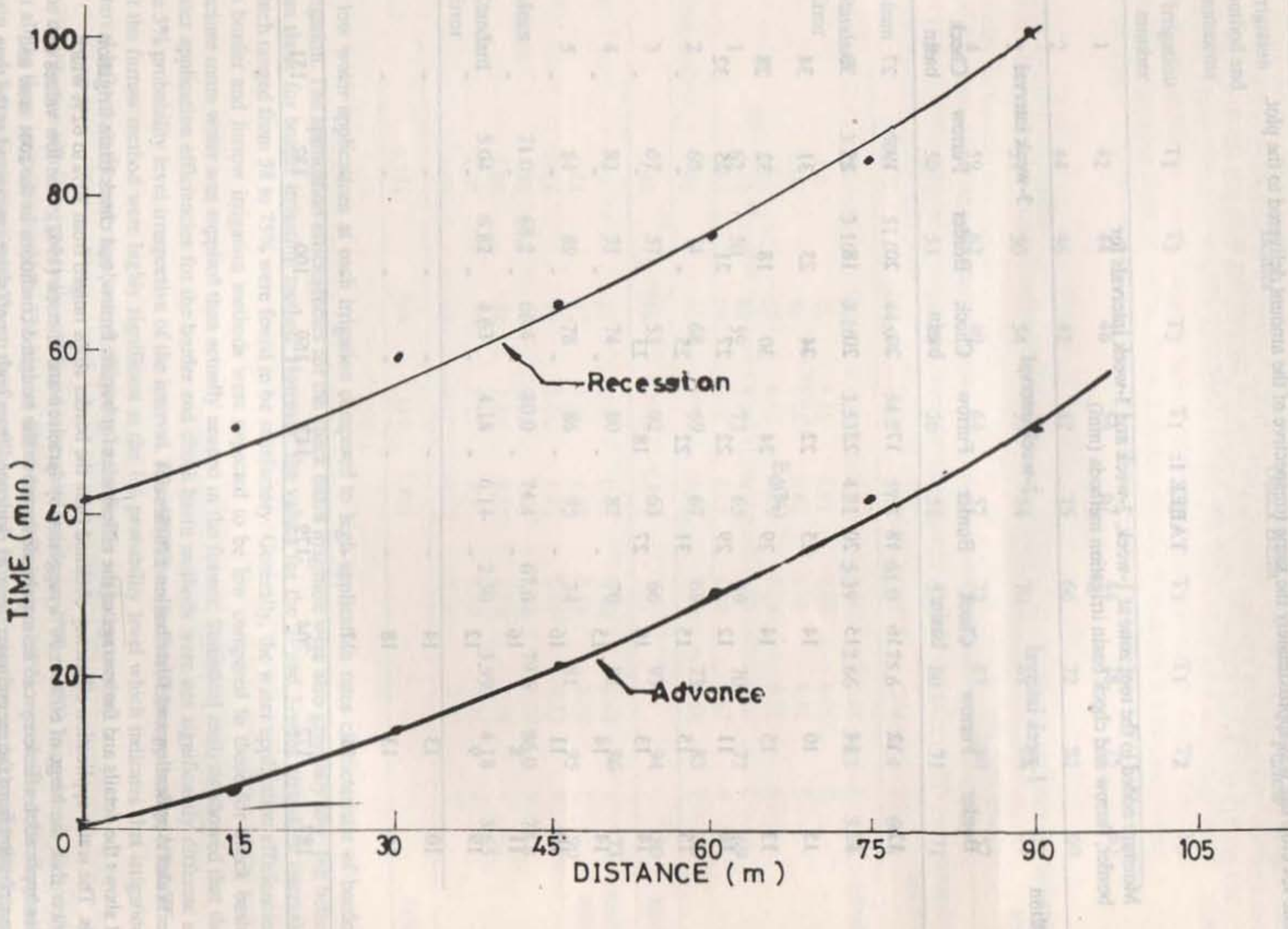

Fig. 4 Advance and recession curve, border strip B-2-1A. For 2 week irrigation interval. 30th January, 1987. (q_o = 3.26 l/s/m, irrig. no 3).

practice, the excess water arising from each irrigation method is expected to be small compared to that to be retained by the rootzone. However, the frequent irrigation practice for the 1-week interval is expected to result in high runoff and deep percolation losses which can lead to significant rise in the water table and hence the water-logging problems being experienced on the field. Table 1 shows that the moisture added to the rootzone at a given interval of irrigation are very close which indicates that the amount of water available for crop use was approximately the same irrespective of the amount delivered to the plot.

TABLE 1:

Moisture added to the root zone at 1-week, 2-week and 3-week intervals for border, furrow and check basin irrigation methods (mm).

Irrigation No.	1-week interval			2-week interval			3-week interval		
	Border	Furrow	Check basin	Border	Furrow	Check basin	Border	Furrow	Check basin
1	12	12	16	18	17	20	20	19	27
2	13	14	15	20	22	20	18	25	30
3	15	10	14	25	22	24	23	31	34
4	13	15	14	29	24	30	18	32	28
5	16	11	12	29	22	27	21	25	32
6	15	15	15	31	22	25	-	-	-
7	14	13	10	27	18	23	-	-	-
8	14	14	15	-	-	-	-	-	-
9	19	11	16	-	-	-	-	-	-
10	11	8	16	-	-	-	-	-	-
11	19	9	12	-	-	-	-	-	-
12	10	13	14	-	-	-	-	-	-
13	16	13	18	-	-	-	-	-	-
14	-	14	17	-	-	-	-	-	-
	187	172	204	179	147	169	100	132	151

3.3 Water Application and Distribution Efficiencies

Table 2 shows the details and the average of the efficiencies for border, furrow, and check basin irrigation methods. The water application efficiency obtained from the border strips ranged from 36% to 62% which were lower than the range of 60% to 90% suggested by Israelson and Hansen (1962). The low values of the water application efficiency can be mainly attributed to the saturated conditions in the root zone and water contribution from the groundwater table, as evidenced from high runoff values measured at the time of irrigation (Dalhat, 1988). Soil sampling in the field indicated that the soil was extremely wet at a depth of 250mm below the soil surface. The water application efficiencies for the furrow irrigation was found to be satisfactory, ranging between 53 to 82% for the various stages of crop growth. This could be attributed

TABLE 2:

Water application (E_a) and distribution (E_d) efficiencies

Irrigation method and treatments	Border			Check Basin			Furrow		
Irrigation number	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
1	42	44	48	54	62	44	78	75	63
2	44	46	42	42	75	66	72	82	60
3	57	50	54	55	54	70	81	64	53
4	59	62	40	64	57	72	67	80	57
5	50	53	36	56	51	53	80	71	71
Mean	50.4	51.0	44.0	54.2	59.8	61.0	75.6	74.4	60.8
Standard Error	3.39	3.16	3.16	3.53	4.21	5.39	2.66	3.23	3.04
					E_d(%)				
1	62	50	59	73	65	59	70	72	69
2	60	74	68	69	67	69	73	83	82
3	67	57	53	92	63	66	93	94	80
4	82	71	74	80	82	70	81	86	73
5	84	89	78	86	95	74	81	95	90
Mean	71.0	68.2	66.4	80.0	74.4	67.6	79.6	86.0	78.8
Standard Error	5.04	6.82	4.63	4.18	6.14	2.50	3.99	4.18	3.65

to low water applications at each irrigation compared to high application rates characteristic of border irrigation. The application efficiciencies for the check basin irrigation were also generally low, but better than those for border irrigation method. However, the values for the 2- and 3-week irrigation intervals which ranged from 58 to 75% were found to be satisfactory. Generally, the water application efficiencies on border and furrow irrigation methods were expected to be low compared to those for check basin because more water was supplied than actually needed in the former. Statistical analysis showed that the water application efficiencies for the border and check basin methods were not significantly different at the 5% probability level irrespective of the interval. The differences in the water application efficiencies for the furrow method were highly significant at the 1% probability level which indicates that irrigation interval influences the water application efficiency in the furrow irrigation method.

The distribution efficiency generally was found to be quite satisfactory. The values ranged from 50 to 95% for all the three irrigation methods. The highest distribution efficiency of 95% was obtained for the check basin and furrow irrigation methods at the 2-week interval. Border irrigation method gave the lowest distribution efficiencies compared to the other two methods. The results of the statistical analysis on the water distribution efficiencies showed that the values did not differ significantly at the 5% probabiblity level irrespective of the interval for the border, check basin and furrow irrigation methods. The uniformity of water distribution is more important than the water application efficiency in terms of maintaining uniform crop growth, thus, all the three methods of surface irrigation performed reasonably well.

3.4 Moisture Contribution from Groundwater

Table 3 gives typical estimates of soil moisture contributions for border and check basin irrigations at 2-week intervals. The estimated moisture contribution from the groundwater table into the root zone was 227, 263 and 311 mm for the 1-week, 2-week, and 3-week border irrigation practices, respectively (Dalhat, 1988).

TABLE 3:

Estimated soil moisture contribution from groundwater at 2-week irrigation intervals for border and check basin

Irrigation Method	(1) i	(2) MC_1	(3) MC_2	(4) S	(5) US	(6) ET_a	(7) ET_a-US
Border	1	23.0	41.3	18.3	-	24	-
	2	19.4	48.9	19.5	21.9	28	6.1
	3	21.4	46.4	25.0	27.5	48	20.5
	4	18.6	47.2	28.6	27.8	82	54.2
	5	20.4	49.2	28.8	26.8	88	61.2
	6	19.2	50.3	31.1	30.0	93	63.0
	7	22.4	49.3	26.9	27.9	86	58.1
Total				178.2	161.9	449	263.1
Check Basin	1	19.4	39.4	20.0	-	24	-
	2	23.4	43.5	20.1	16.0	28	12.0
	3	18.4	42.7	24.3	25.1	48	23.0
	4	19.2	48.7	29.5	23.5	82	58.5
	5	20.4	47.2	26.8	28.3	88	59.7
	6	24.5	49.3	24.8	22.7	93	70.3
	7	23.4	46.2	22.8	25.9	86	60.1
Total				168.3	141.5	449	283.6

Col. 1 - Irrigation number
Col. 2 - Moisture content before irrigation
Col. 3 - Moisture content after irrigation
Col. 4 - Moisture added to the rootzone (Col. 3 - Col. 2)
Col. 5 - Estimated water used, $MC_2(i) - MC_1(i+1)$
Col. 6 - Actual evapotranspiration before next irrigation
Col. 7 - Estimated moisture contribution from groundwater table.

In the furrow irrigation method, the groundwater contribution was 288 mm for 1-week, 300 mm for 2-week and 304 mm for the 3-week irrigation intervals. The crops under the 2-week and 3-week irrigation interval treatments were observed to be water-stressed which resulted in reduced grain yield.

The contribution from the groundwater was estimated to be 259, 284 and 293 mm for the 1-week, 2-week and 3-week check basin irrigation intervals, respectively. Since, in the check basin irrigation method, no runoff takes place and all the water introduced is absorbed, the deep percolation losses are expected to be high if excessively large basin sizes and/or stream sizes are used. The relatively low level of moisture contribution from the water table for the check basin method indicates that the basin sizes of 5m by 5m have been adequate.

A serious consideration has not been given to the importance of groundwater contribution in irrigation scheduling and practice in the Kadawa project and so an arbitrarily-fixed irrigation interval of 7 days is being used throughout the growth period for all crops. The result has been a steady rise in the water table depth over the years which continues to worsen the waterlogging and salinity problems in the area. Dalhat (1988) found that the border irrigation method did not given suitable water table depths of 700 to 500mm recommended for wheat growth by Williamson and Kriz (1970). The check basin gave an average water table depth of 560mm for the 2-week irrigation interval while the 1-week interval for furrow irrigation gave the highest water table depth of 500mm. Thus, it is seen that the 2-week check basin and 1-week interval for the furrow irrigation methods gave the recommended water table depths suitable for wheat growth.

3.5 Crop Yield Measurements

The grain yields for the different irrigation methods and intervals are given in Table 4. Statistical analysis showed that the effects of irrigation method on grain yield was highly significant at 1% probability level, irrespective of the interval. The difference in yield between the check basin and furrow methods was not significant but border irrigation differs from the others giving lower yields.

TABLE 4:

. **Effects of irrigation methods and intervals on grain yield (t/ha)**

Irrigation method	Irrigation Treatment		
	T_1	T_2	T_3
Border	1.95	2.0	1.19
Furrow	3.79	1.79	0.823
Check basin	2.10	3.14	1.18
LSD		0.05	
Method		0.454	
Method x Interval		0.134	

The effects of the irrigation intervals showed that there was no significant difference between the 1-week and 2-week irrigation intervals, but the 3-week interval was found to be significantly different from others. The yield for the 3-week interval was very low indicating high water stress on the crops at the stages which are highly sensitive to water stress such as the flowering stage.

4. CONCLUSIONS

The following conclusions can be made from the study presented herein:

1. The 1-week interval for furrow irrigation was the most ideal of the treatments as it gave the highest grain yield and a root zone depth satisfactory for wheat growth.

2. The check basin method performed better than the border at the 2-week interval. The performances were generally not good at the 3-week intervals for the three methods.

3. It is recommended that the 2-week irrigation interval be adopted for check basin and border and 1-week interval for the furrow irrigation practices in the area.

4. The best method of irrigation in the long run for the area is the check basin as it eliminates the need for extensive land levelling often required in the other methods in order to ensure high uniformity of water application.

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THE EFFECTS OF NITROGEN SOLUBILITY OF HEAT PROCESSING ALFALFA HERBAGE

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Abstract

Soft-centre, high moisture (>46%, moisture) large round bales of alfalfa herbage were heat-processed in a fan/heater apparatus to investigate the effect of forced air heat treatment on nitrogen solubility. Treatment times were either 90 or 120 min at air temperatures of between 70°C and 80°C (established from preliminary investigations). The controls and heat treated materials were either ensiled or frozen. Hot Water Soluble Nitrogen (HWSN) was affected by duration of treatment, form of treatment, position (radial) and axial distances across the bales. Heat-processing large round bales prior to ensiling decreased the concentration of HWSN in both ensiled and frozen material. Heat-treatment reduced proteolysis (protein breakdown) by 30 and 36% when ensiled or frozen, respectively, compared to the controls. The highest reduction was in samples heated for 120 min. Repeatability of heat-processing large round bales in the fan/heater unit prior to ensiling was found to be feasible since HWSN was not different ($P<0.05$) between 1989 and 1990 experiments. The research emphasizes the scope for improving the protein quality of forage herbages.

KEYWORDS: Bales, Alfalfa, Heat-processing, Silage crude protein, Hot water, soluble (insoluble) nitrogen.

1. INTRODUCTION

The crude protein content of early-cut alfalfa and alfalfa/grass forage stored as silage exceeds the recommended requirements for young growing ruminants (NRC, 1984). Nevertheless, recent studies have shown a marked improvement in the performance of growing calves fed either early-cut wilted alfalfa/grass silages (Mowat and Buchanan-Smith, 1988; Bilanski *et al.*, 1990) or direct-cut grass silages supplemented with protein sources of low rumen degradability (Veira 1987). This is due to the fact that forage protein undergoes extensive degradation during the ensiling process (Flores *et al.*, 1986).

Chemicals such as formic acid, formaldehyde and ammonia have been used as additives during ensiling to improve nitrogen utilization (Thomas and Thomas, 1985; Glenn and Waldo, 1986). However, these additives do not always prevent extensive proteolysis during ensiling (McDonald, 1981) nor improve animal performance (Glenn and Waldo, 1986). Wilting alone has been observed to have no effect on proteolysis during the ensilage process (Young, 1971; Papadaopoulus, 1983). Another alternative is heat processing of forages prior to ensiling. Charmley and Veira (1987) demonstrated that steam treatment (60 s duration) of alfalfa prior to ensiling inhibited proteolysis and markedly improved the utilization of silage nitrogen. Mandell *et al.* (1990) found that heat treatment increased the insoluble nitrogen content of alfalfa silage without inducing heat damage. However, previous studies have tended to focus on small quantities of the experimental material.

The objective of this study was to determine the effects on nitrogen solubility of heat-processing moist soft-centre large round bales of alfalfa forage.

2. MATERIALS AND METHODS

2.1 Equipment and Sampling

A commercially-available fan-heat unit, model U-1028BG, manufactured by Farm Fans Inc., Indiana, USA, designed for agricultural use in fill-and-dry and batch drying systems was used. The unit consists essentially of a fan/heater housing, axial fan, single-phase 230 volt motor, control box, thermostat, vaporizer and gas (fuel) supply system. In order to use the fan/heater unit to meet the specific requirement of this study, certain devices such as fan/heater outlet duct extension, heat/air resistant canvas, platforms and roof were designed and fabricated for connecting the fan/heater unit to large round bales. The schematic diagram of layout of the fan/heater apparatus is shown in Fig. 1 while the details are presented in Yiljep (1991).

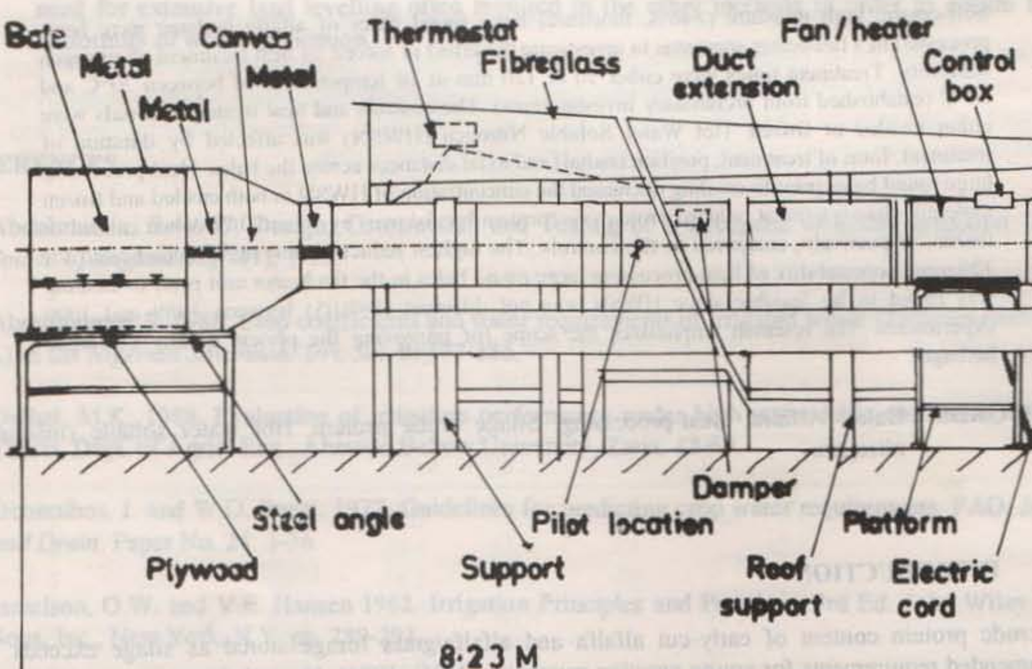

Fig. 1: Schematic view of fan/heater experimental apparatus.

A variable chamber baler (MOdel RP-15), Mckee, Elmira, Ontario, Canada) was used to form standard soft-centre, 1.22m long and 1.52m diameter, large round bales of alfalfa at various moisture contents (ranging from 46 to 60%, wet basis, depending on how long the herbage was wilted in the field) in the summers of 1989 and 1990. Following baling, each bale was transported to the experimental site (Arkell Research Station) and dimensions of the bales were recorded. Initial and after-treatment weights of the bales were obtained using a commercial weighing scale (Gurney Scale, Model 60262). Thermocouples were inserted into holes that were previously created by forcing a metal probe 8 mm diameter and longer than the diameter of a bale) and spaced at an incremental distance of 30.5 cm across the length of the bale and 19.0 cm, 138cm and 76cm into the bale in each position (See Fig. 2). A set of 11, type T Copper-constantan thermocouples were used for temperature measurement. Nine were inserted into the bale in the above-mentioned positions, one placed outside and the other fixed to the centre of the inlet of the bale. Thermocouples recorded bale temperature with respect to position and time; they rcorded ambient temperature and the temperature of the incoming hot air being forced through the bale over the same time period. All thermocouples were calibrated before commencement of each experiment.

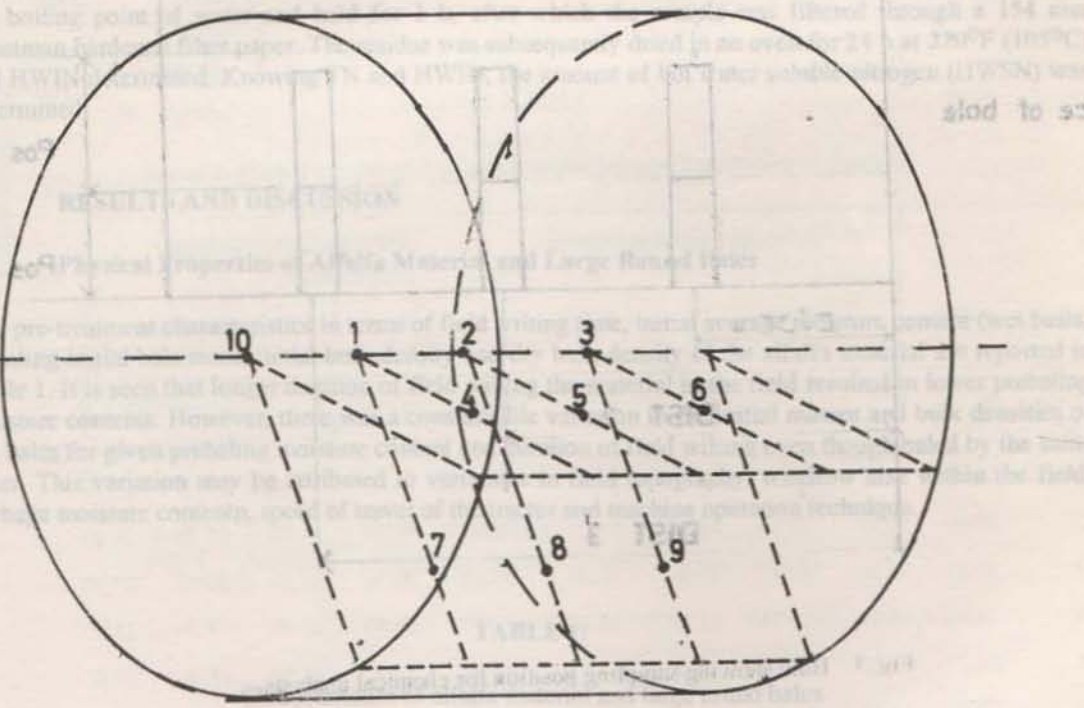

Fig. 2: Schematic view of bale showing temperature measurement positions.

Temperature measurements were monitored continuously for either 90 or 120 min at one minute intervals using a multi-channel data logger (Doric data loger, model 245, Becman Industrial Intertechnology Inc., Don Mills, ON.). A small portable computer, Tandy 200, was connected to one of the Doric's serial ports and programme to receive and store data from the data logger. The data in the Tandy 200 files were later uploaded into an IBM personal computer, transferred to diskettes and stored for later processing. The bales were heat-treated for either 90 or 120 min at air temperaturs of between 70°C and 80°C (established from preliminary investigations). Samples of alfalfa material randomly picked from the field prior to baling (to serve as controls) were either ensiled or frozen immediately or heat-treated and then ensiled or frozen. Heat treatment was carried out in two standard conventional ovens (Cole-Parmer and Quincy Ovens, both manufactured in Chicago, Illinois) in the laboratory at two temperature settings (80°C and 50°C - range of temperature settings in the fan/heater experiment) for 24 h.

At the end of heat treatments and after recording final bale weights, core samples were taken using a core sampler, Kaylon forage sampler (Kaylon Product Limited, Guelph ON.), 2.54 cm inner diameter and 50 cm long. Sampling was carried out at three distances, DIST 1, DIST 2 and DIST 3 corresponding to 30.5 cm, 61 cm, and 91.5 cm, along bale axial length respectively (corresponding to sections or planes where thermocouples were positioned). Core samples were taken at two positions, POS 1 and POS 2 corresponding to 0-25 cm from the bale surface and 25-50 cm from the bale surface radially into the bale.

respectively (See Fig. 3). From experience, it was found that attempting to cut the bale longitudinally resulted in no cutting but merely pushing the material aside.

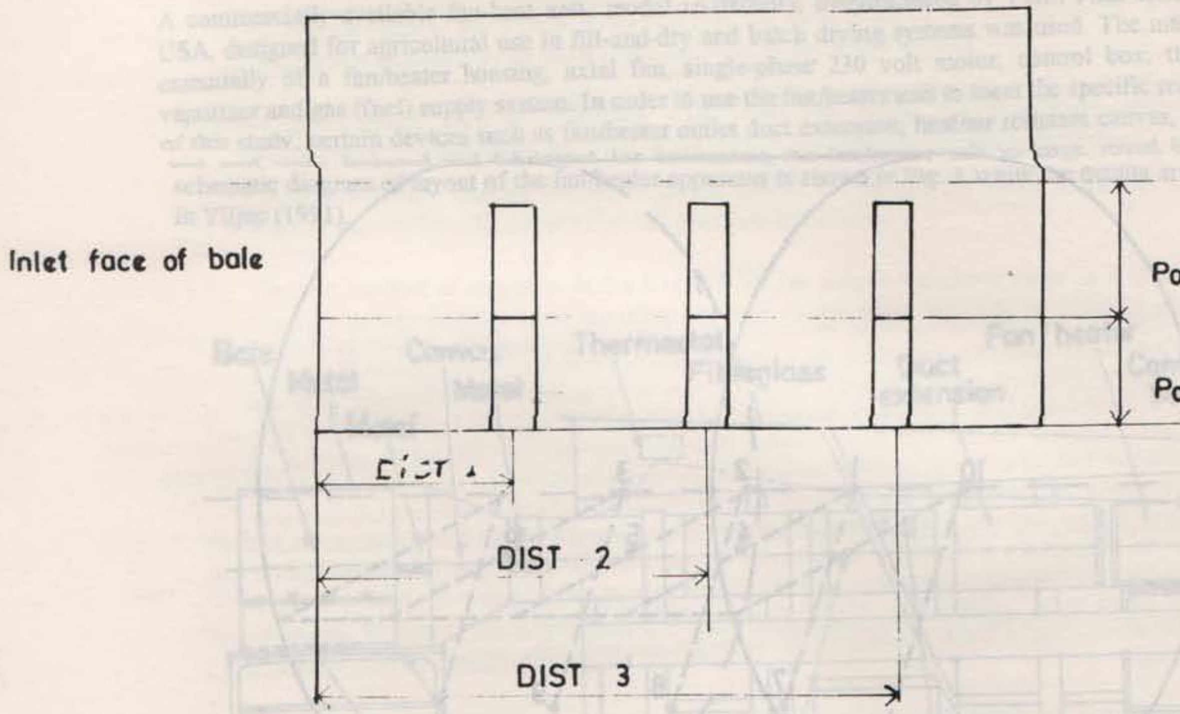

Fig. 3. Bale showing sampling position for chemical analysis

Six samples were obtained from each bale for chemical analysis, while eight samples, taken at random in each bale were set aside for after-treatment moisture content determinations. Each sample for chemical analysis was divided in two parts. One part marked for ensiling was quickly and tightly packed in 500 ml standard Mason glass jars, sealed and stored under room temperature for about 35 days. The remainder was packed in polythylene bags and kept frozen at -30^{o}C in a refrigerator for the 35 days prior to chemical analysis.

2.2 Moisture Content and Dry Matter Determination

2.2.1 Chemical analysis

Initial and final moisture contents of the bales were determined according to the American Society of Agricultural Engineer's Standard: ASAE (1986) S358.1. Predetermined wet weights, about 50g of each sample, were oven dried at 103^{o}C for 24 h in a standard Fisher Isotemp. Oven. At the end of heat treatment, the final weights of the samples were obtained and their moisture contents calculated. Approximately 1 g of each sample was weighed, placed in an oven and heated for 2 h at 135^{o}C. The sample was weighed again after heating and dry matter content determined.

2.2.2 Total Nitrogen

Samples for Total Nitrogen (TN) were refrigerated at -37^{o}C, freeze-dried for 24h in Virtis Sublimator Freeze-drier (model 50-SRC), and ground to pass through a 1 mm screen. Approximately, 1g of each sample (analyzed in duplicate) was weighed and the crude protein determined by the Macro-Kjeldahl method (AOAC, 1980).

2.2.3 Hot Water Insoluble Nitrogen

Hot Water Insoluble Nitrogen (HWIN) was obtained by the standard Macro-Kjeldahl Method (AOAC, 1980). Each sample was initially subjected to the same weighing and processing procedures as outlined above. Approximately 100 ml of distilled water was added to the sample in a 600 ml pyrex glass, heated to the boiling point of water and held for 1 h, after which the sample was filtered through a 154 mm Whatman hardened filter paper. The residue was subsequently dried in an oven for 24 h at 220°F (105°C) and HWIN determined. Knowing TN and HWIN, the amount of hot water soluble nitrogen (HWSN) was determined.

3. *RESULTS AND DISCUSSION*

3.1 Physical Properties of Alfalfa Material and Large Round Bales

The pre-treatment characteristics in terms of field wilting time, initial average moisture content (wet basis) at baling initial bale mass, initial bulk density and dry bulk density of the alfalfa material are reported in Table 1. It is seen that longer duration of field wilting the material in the field resulted in lower prebaling moisture contents. However, there was a considerable variation in the initial masses and bulk densities of the bales for given prebaling moisture content and duration of field wilting even though baled by the same baler. This variation may be attributed to variations in field topography, windrow size within the field, herbage moisture contentn, speed of travel of the tractor and machine operation technique.

TABLE 1:

Characteristics of alfalfa material and large round bales

Bale No.[a]	Duration of Wilting (days)	Initial moisture content (%)	Initial Weight (kg)	Initial bulk density (kg/m^3)	Dry bulk density (kg/m^3)
1	1.50	60.0	520	234	93.6
2	2.00	48.2	460	207	107.2
3	1.75	54.5	580	261	118.8
4	2.00	47.5	590	265	139.1
5	1.50	58.4	490	220	[illegible]
6	1.75	53.6	470	211	97.9
7	1.50	52.0	522	235	112.8
8	1.50	52.0	524	236	113.3
9	1.0	59.5	550	248	100.4
10	1.0	57.6	476	214	90.7
11	1.75	47.3	533	240	126.5
12	1.75	47.0	442	199	105.5

[a] Bales 1 to 6 are from 1989 experiments and 7 to 12 from 1990 experiments.

3.2 Temperature Variation During Heat Treatment

Sample plots of average temperature changes with position and time in three planes (distances), plane 1, plane 2 and plane 3 corresponding to thermocouple's positions 147, 258 and 369 from the inlet faces of the bales, respectively) across axial lengths of bales 1 and 4 together with temperature variations of the incoming hot air and ambient temperature, all monitored over the same heating period are shown in Figs. 4 and 5. Average initial and after treatment temperatures for all the bales investigated are shown in Table 2.

TABLE 2:

Average exposure and forage temperatures during heat treatment of bales

	Average bale temperature						Average heater/ambient temperature			
	147c		258		369		Heater temperature		Ambient temperature	
Bale No.	a*	b**	a	b	a	b	a	b	a	b
1	28.73	52.97	28.73	50.50	36.60	41.67	26.70	51.40	24.70	26.70
2	20.60	50.57	20.80	48.83	20.20	46.63	15.30	49.80	25.70	26.40
3	27.87	50.50	37.63	42.40	40.07	39.63	30.30	67.10	26.60	29.10
4	24.50	63.57	22.73	55.37	24.30	43.77	26.80	60.10	25.70	23.00
5	26.77	53.07	33.57	48.20	37.00	44.97	27.30	68.30	29.20	24.41
6	25.77	52.43	27.88	49.60	26.48	46.97	22.90	56.20	24.20	25.91
7	40.93	45.97	41.53	39.90	36.23	34.90	25.80	78.40	24.30	22.90
8	28.13	48.80	31.48	41.80	25.83	39.13	31.60	65.00	28.30	26.60
9	27.03	40.50	31.00	38.90	31.43	32.93	25.30	72.60	27.50	25.80
10	31.58	54.67	32.23	48.77	23.10	44.53	26.60	67.00	24.90	24.80
11	29.13	53.60	29.58	45.03	28.73	35.93	23.00	70.40	24.40	19.10
12	35.08	48.00	40.30	43.37	29.77	37.73	25.00	66.00	26.70	25.30

* Initial average temperature
** Final average temperatures
Thermocouple positions
147 - plane 30 cm from air inlet
258 - plane 60 cm from air inlet
369 - plane 90 cm from air inlet.

It is observed in the plots that there is a definite trend in temperature rise across the three planes in a bale, with the highest occuring during initial warm-up periods, then becoming almost linear in later periods of continuous heating. Similar trends were observed when averages were plotted for three planes in the radial directions (centre of bale - positions 123, mid-way between centre and denser outlet portion - positions 456, and denser outer portion - positions 789).

Higher temperatures were recorded at planes nearer the source of incoming hot air, then decreasing towards the exit faces of the large round bales. However, a close examination of the temperature data (see Yiljep, 1991) showed that in general, the rise was much higher in the axial centres of the bales and decreasing towards the denser radial portions. This confirms the fact that soft-centre large round bales are denser at their peripheries than in their raidal centres.

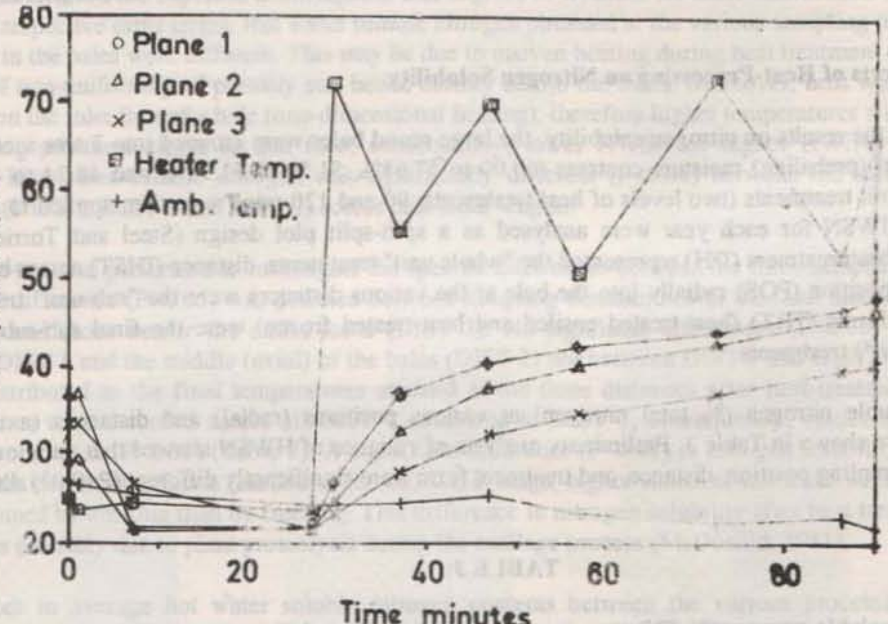

Fig. 4: Pattern of temperature variation during heating (bale 1)

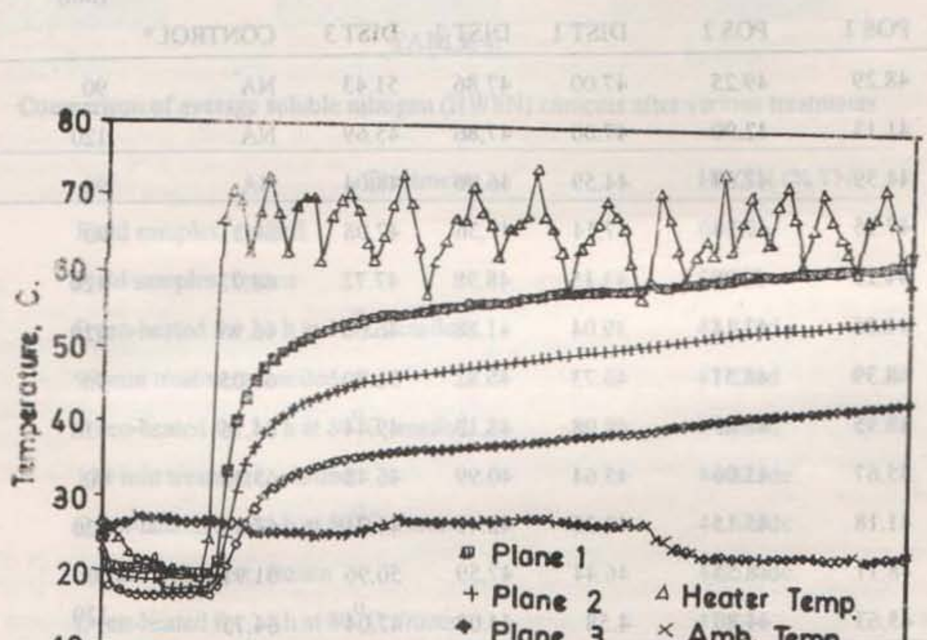

Fig. 5: Pattern of temperature variation during heating (bale4)

Forcing ambient air (with heater not operating) through the bales decreased the initial temperatures across the three planes in the bales (depicted by the sharp declines) (Figs 4 and 5), and in fact, in all the temperature - sampling positions across the bales. The decrease in ambient temperature and the 0N-OFF cycling of the heater as depicted by the variation of the temperature of the incoming hot air (with heater operating within set limits), had little or no effect on temperature changes at the various positions inside the bales.

3.3 Effects of Heat-Processing on Nitrogen Solubility

In analysing the results on nitrogen solubility, the large round bales were grouped into 3 sets according to similar initial (prebaling) moisture contents (60.00 to 57.65%, 54.50 to 51.98%, and 48.24 to 46.97%). The whole unit treatments (two levels of heat treatments, 90 and 120 min) were then applied to each set. Results of HWSN for each year were analysed as a split-split plot design (Steel and Torrie, 1980). Duration of heat treatment (DH) represented the "whole unit" treatments, distance (DIST) across bale axial lengths and position (POS) radially into the bale at the various distances were the "sub-unit" treatments, and storage forms (TRT) (heat-treated ensiled and heat-treated frozen) were the final sub-sub-division ("sub-sub-unit") treatments.

Average soluble nitrogen (% total nitrogen) at various positions (radial) and distances (axial) after treatments are shown in Table 3. Preliminary analysis of variance of HWSN showed that duration of heat treatment, sampling position, distance, and treatment form were significantly different (P<0.01) during

TABLE 3:

Average soluble nitrogen (% TN) at various positions (radial) and distances (axial) after treatments.

Bale No.	Sampling Positions[a]		Sampling Distances[b]				Treatment (mn)
	POS 1	POS 2	DIST 1	DIST 2	DIST 3	CONTROL*	
1	48.29	49.25	47.00	47.86	51.43	NA	90
2	41.13	42.90	47.00	47.86	45.69	NA	120
3	44.59	47.54	44.59	46.96	48.04	NA	90
4	47.15	47.24	47.14	47.36	47.08	68.21	90
5	44.25	48.98	43.15	48.98	47.72	68.72	120
6	41.86	43.14	39.04	41.88	46.60	66.95	120
7	48.39	48.51	46.73	46.82	51.80	60.05	90
8	48.95	48.82	49.08	48.13	49.44	64.16	120
9	45.67	43.06	45.64	40.99	46.48	65.35	90
10	41.18	45.15	42.36	42.41	44.71	67.53	120
11	48.11	48.55	46.44	47.59	50.96	61.91	90
12	45.63	44.80	4.58	44.02	47.04	64.73	120

a = Sampling positions, average of three samples
POS 1 = 0.25 cm radially into bale
POS 2 = 25-50 cm radially into bale
b = Sampling distances, average of two samples
DIST 1 = 30.5 cm from inlet face of bale (axially)
DIST 2 = 61 cm from inlet face of bale (axially)
DIST 3 = 91.5 cm from inlet face of bale (axially)
* = Field samples, ensiled, average of three samples.

heat treatment for both 1989 and 1990 high-moisture, soft centre large round bales. However, the only significant interaction ($P<0.01$) detected in 1989 was between DH and TRT (DH x TRT). There were no other differences in treatment effects in two years of the study; hence, data from the two years were combined and analyzed as a series of experiments in a split-split-plot design as a was done for each year.

During preliminary analysis of variance for data as a series of experiments. the absence of any higher order interactions allowed the expected mean squares and degrees of freedom for those interactions to be pooled into their respective error terms. Hot water soluble nitrogen obtained at the various sampling positions and distances in the bales were different. This may be due to uneven heating during heat treatment of the bales, a result of non-uniformity of porosity and hence density across the bales. Moreover, heat was constantly supplied on the inlet face of a bale (one-dimensional heating), therefore higher temperatures were recorded at sampling positions closer to that face; consequently, lower HWSN or higher HWIN values were obtained. Hot water soluble nitrogen was significantly different ($P<0.01$) between the three sampling distances (DIST 1, DIST 2 and DIST 3) across bale axial lengths.

A paired t-test was performed to investigate the specific differences between the three sampling distances. A HWSN difference ($P<0.05$) was detected between sampling distance nearer the inlet faces of the bales (DIST 1) and those nearer the outlet faces (DIST 3). No signficant differences ($P<0.05$) were found between DIST 1 and the middle (axial) of the bales (DIST 2) nor between DIST 2 and DIST 3. This again may be attributed to the final temperatures attained at the three distances after heat-treatments. Higher temperatures were recorded across all DIST 1 compared to DIST 3; consequently, values of HWSN at DIST 1 were lower ($P<0.05$) (Table 3). A significant difference ($P<0.01$) in nitrogen solubility was found between the two storage forms (ensiled vs frozen). On average, higher values of hot water soluble nitrogen were obtained by ensiling than by freezing. This difference in nitrogen solubility after heat treatment upon ensiling is probably due to plant proteolysis during the ensilage process (McDonald, 1981).

Differences in average hot water soluble nitrogen contents between the various processing methods employed in this study were investigated using Duncan's multiple range test. The results of the analysis are shown in Table 4. It is seen that:

TABLE 4:

Comparison of average soluble nitrogen (HWSN) contents after various treatments

	Treatments	HWSN (% TN)
1.	Field samples, ensiled	66.05a
2.	Field samples, frozen	56.86b
3.	Oven-heated for 24 h at 50°C, ensiled	47.41cd
4.	90 min treatment, ensiled	47.23cd
5.	Oven-heated for 24 h at 80°C, ensiled	46.43cd
6.	120 min treatment, ensiled	44.82cde
7.	Oven-heated for 24 h at 50°C, frozen	44.63cde
8.	90 min treatment, frozen	44.53cde
9.	Oven-heated for 24 h at 80°C, frozen	42.20e
10.	120 min treatment, frozen	37.87f

Data followed by the same letters do not differ ($P<0.05$) according to Duncan's multiple range test.

1. The average HWSN content of field-sampled and ensiled alfalfa (without heat treatment) is higher than the average for all other treatment methods.
2. The average HWSN content of field-sampled and frozen alfalfa (without heat treatment) is higher than the average for all other treatment methods except for 1 above.
3. There was no difference between average HWSN contents of ensiled alfalfa heat-treatment in standard conventional ovens and in the fan/heater apparatus. However, the values are different (higher) than the correspondingly heat-treated and frozen samples.
4. The lowest average HWSN content was obtained from bale samples that were heat-treated for 120 min and frozen. Fig. 6 shows comparisons of average HWSN (%TN) contents of storage forms for the various processing methods investigated in this study.

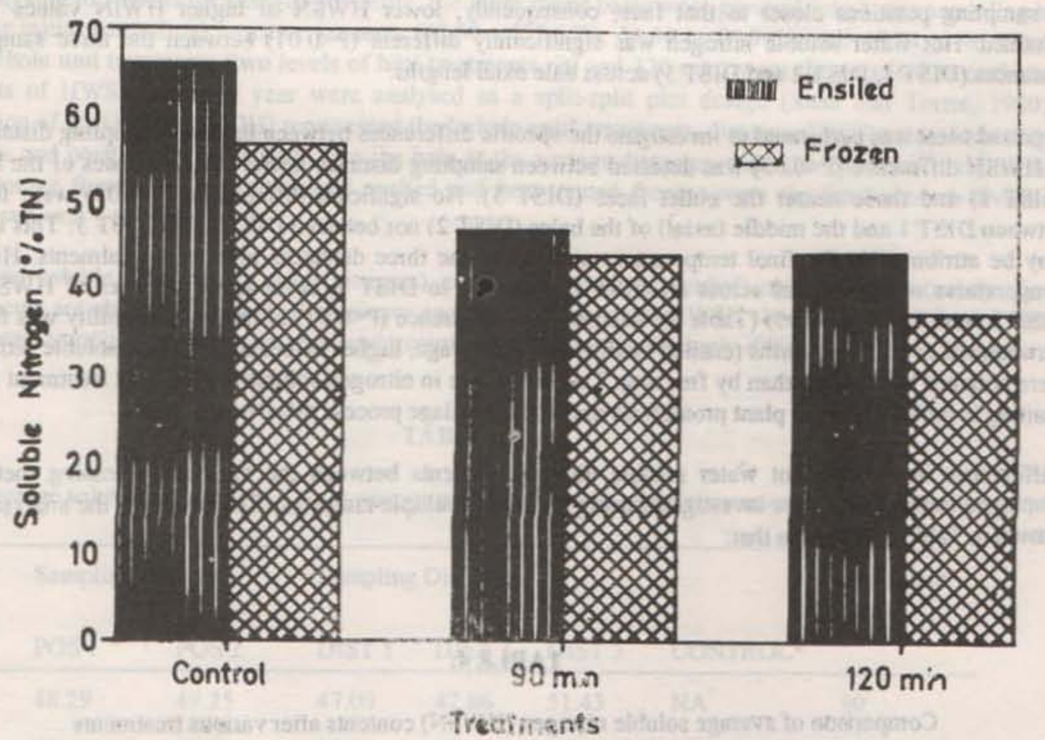

Fig. 6: Hot water soluble nitrogen content of alfalfa herbage after various treatment.

The difference (P<0.05) in HWSN contents between the controls and the other processing methods investigated in this study suggests that heat processing alfalfa prior to ensiling or freezing decreased the concentration of HWSN and conversely, increased HWIN content. Taking the HWSN of an untreated (control-directly from the field) ensiled sample as the base, 30 and 36% reduction in proteolysis were achieved after heat treatment in ensiled and frozen samples, respectively. This confirms the findings of previous researchers (Papadopoulos and McKersie 1983); Mandell *et al.*, 1989; Charmley and Veira, 1990).

Fig. 7 shows a comparion of percentage reduction in HWSN obtained during heat-processing of alfalfa by the various methods, taking the control as the standard. Overall, a significant reduction of HWSN was achieved as a result of heat-processing. According to Charmley and Veira (1990), heat-treatment reduces proteolysis during the ensilage process, resulting in higher concentrations of insoluble nitrogen and lower concentrations of ammonia nitrogen. Papadopoulos and McKersie (1983) found that hydrolysis of protein during the ensiling process was due to plant enzyme action while ammonia formation was due to the combined action of both plant and microbial enzymes.

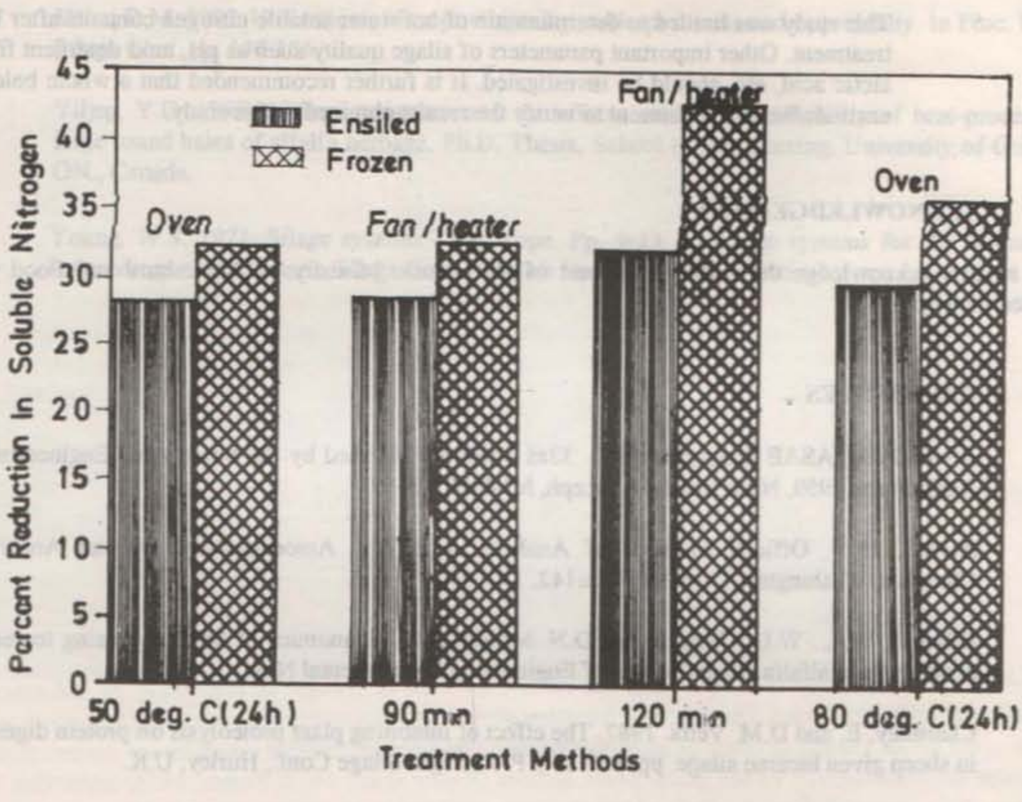

Fig. 7: Reduction in soluble nitrogen by various treatments (taking ensiled field sample as the basis)

The differences in nitrogen solubility due to heat processing high moisture, soft-centre large round bales of alfalfa in the present study are quite similar to those of heat processed silages reported by Charmley and Veira (1987) and Mandell *et al.* (1990). However, hot water soluble nitrogen contents of the controls (frozen samples) obtained in this study were higher than the corresponding values reported by the researchers. This may be attributed to proteolysis occuring as a result of delay in freezing the field samples immediately.

4. CONCLUSIONS AND RECOMMENDATIONS

High moisture soft-centre large round bales of alfalfa herbage were heat-processed in a fan/heater unit and in standard conventional ovens in 1989 and 1990. Air and herbage temperatures were measured during heat-processing. Chemical analyses were conducted on after-treatment samples and the controls.

Based on the results of this study the following conclusions can be drawn:

1. Higher temperatures were recorded around the axial centres compared to outer denser radial portions of the large round bales. This confirms the fact that soft-centre large round bales are denser at their peripheries than in their radial centres.
2. Hot water soluble nitrogen content of soft-centre large round bales of alfalfa herbage is affected by duration of heat treatment, positions (radial), distances across bale axial lengths and form of treatment.
3. Hot water soluble nitrogen was higher ($P<0.05$) in samples obtained from the field prior to baling and ensiled or frozen compared to all those heat-treated and ensiled or frozen.
4. Repeatability of hot air treatments of large round bales of alfalfa herbage in the fan/heater unit used in this study prior to ensiling is possible since no significant difference in hot water soluble nitrogen was found between the two years of the experiment.

5. This study was limited to determination of hot water soluble nitrogen contents after heat treatment. Other important parameters of silage quality such as pH, acid detergent fibre, *lactic acid, etc. should be investigated. It is further recommended that a whole bale be* ensiled after heat treatment to verify the results obtained in this study.

5. ACKNOWLEDGEMENT

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A DEVICE FOR SHEAR FRACTURE EVALUATION OF SOYBEANS

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Abstract

A device for shear fracture evaluation of grain kernels was designed, constructed and evaluated. The equipment employs the principle of the pendulum to shear single kernels, and incorporates features such as a rotary variable differential transformer (RVDT)" to translate the angular mechanical input into linear electrical output. A holder with epoxy cement was used to secure the kernels without damaging them. The instrument was sensitive to change in kernel size, variety and position of impact. Also, results showed that interaction between size and position of impact were significant.

KEYWORDS: Soybeans, Seed grains, Fracture, Mechanical properties.

1. INTRODUCTION

Crops are subjected to considerable handling from their time of harvest to processing or utilization as animal feed or food for man. During these handling operations, grains experience repeated impacts which cause some of the kernels to crack or split completely. The resultant broken materials are undesirable and diminish the marketability of the grain. Some authors (Keller *et al.*, 1972; Foster, 1975) agree that most damage that occur during harvesting and handling are attributable to random impacts. Hence test devices employing purely random impact modes of loading have become popular in predicting breakage tendency of grains, such as corn (Singh and Finner, 1983) and soybeans (Asota, 1984). Other methods which include crushing, cutting, pearling, grinding and indenting are also used to indicate seed quality. There is now considerable interest in determining the fracture property of grains with a view to predicting whether they are safe from fracture during the various handling processes. Fracture properties of seeds are needed by grain millers for the design of efficient milling systems that reduce power requirement downtime. The objectives of this study were therefore to develop equipment and techniques for measuring the resistance of grains to fracture.

2. MATERIALS AND METHODS

2.1 Equipment Description

The apparatus used in measuring the impact energy absorbed by a kernel is shown in Figure 1. An important and unique feature of this device is that two different methods can be used to hold the kernel. It is possible to hold the kernel directly between the jaws of a vise (Figure 2a) as has been the usual practice. While this allows quick measurements, it does not eliminate the possibility of kernel damage by excessive pressure on the kernel prior to the test. Also there can be inadequate clamping while trying to avoid kernel damage. An alternative method which eliminates kernel damage consists of the use of a very fast setting adhesive to bond the kernel in the hole of a wooden block which is then held in position by the vise (Figure 2b). One such cement that proved successful in binding soybeans to wood was "Devcon Epoxy Adhesive" (Devcon Corporation, Danvers, MA). This epoxy provided a firm bond in five minutes. All of the wooden blocks with kernels cemented in can be prepared in one sequence for an entire test series since both blocks and kernels are expendable.

The pendulum consists of a hammer mounted on the shaft of a rotary variable differential transformer (RVDT) (Model RD3, manufactured by Transducers and Systems, Inc., North Bradford, CT -USA). The RVDT is supported by an upright welded to a steel plate. The pendulum is held in an initial position and after fracture of the specimen is sensed by the RVDT which translates the rotary input into linear electrical output. The peak electrical voltages of the output may be recorded with an oscilloscope, a chart recorder, or a maximum/minimum digital voltimeter.

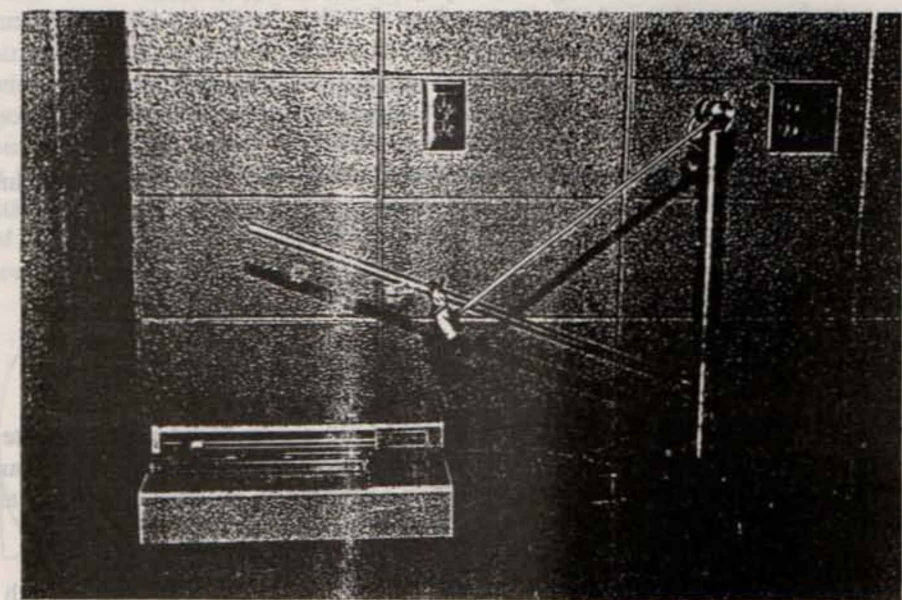

Fig. 1: Pendulum shear device and recorder.

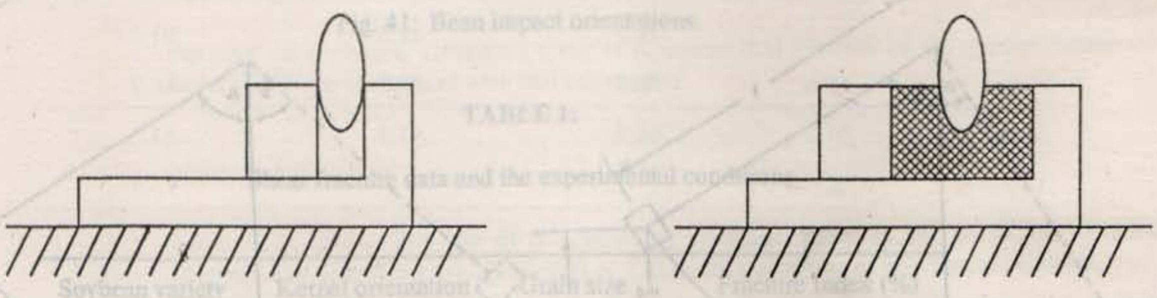

Fig. 2: Kernel holding arrangement..

In the raised initial position, the pendulum has potential energy. When it is released, it swings downward and transmits part of this energy to the specimen. The height to which the pendulum rises after striking the specimen is a measure of its residual or rebound energy. The shear resistance corresponds to the energy absorbed in shearing the specimen and is equal to the difference between the kinetic energy in the pendulum at the instant of impact and the energy remaining in the pendulum after shearing the specimen. This may be computed as follows:

Initial energy, $E_i = MgH = MLg(1 - \cos A)$ (1)

Energy after shear, $E_f = MgH' = MLg(1 - \cos B) + F$ (2)

Energy to shear the specimen, $E_s = MLg(\cos B - \cos A) - F$ (3)

where

M = mass of pendulum

A	=	angle of fall
B	=	angle of rise
L	=	distance from center of gravity of pendulum to axis of rotation.
F	=	energy loss due to air drag and friction
g	=	acceleration due to gravity
H	=	Height of fall of centre of gravity of pendulum
H'	=	Height of rise of centre of gravity of pendulum.

Since the length of a pendulum device is critical in its performance, the length (L) of the pendulum is determined by measuring the period (T) of the pendulum and solving the equation

$$T = 2\pi(L/g)^{1/2} \quad (4)$$

Transposing we have

$$L = 0.81T^2 \quad (5)$$

Typically, a pendulum length of about 380 mm and mass of about 120 g were found to be adequate for shearing soybeans. The period T was determined by allowing the pendulum to swing through a small angle (not over 10^o - 15^o) for about 50 complete oscillations. It was necessary to do several replications to obtain a reliable value.

Energy loss due to air drag and bearing friction were determined by letting the pendulum fall through the same angle but without placing a specimen in the vice (Fig. 3). These were found to be less than one percent of the shear energy of a grain kernel, and therefore may be neglected for this apparatus.

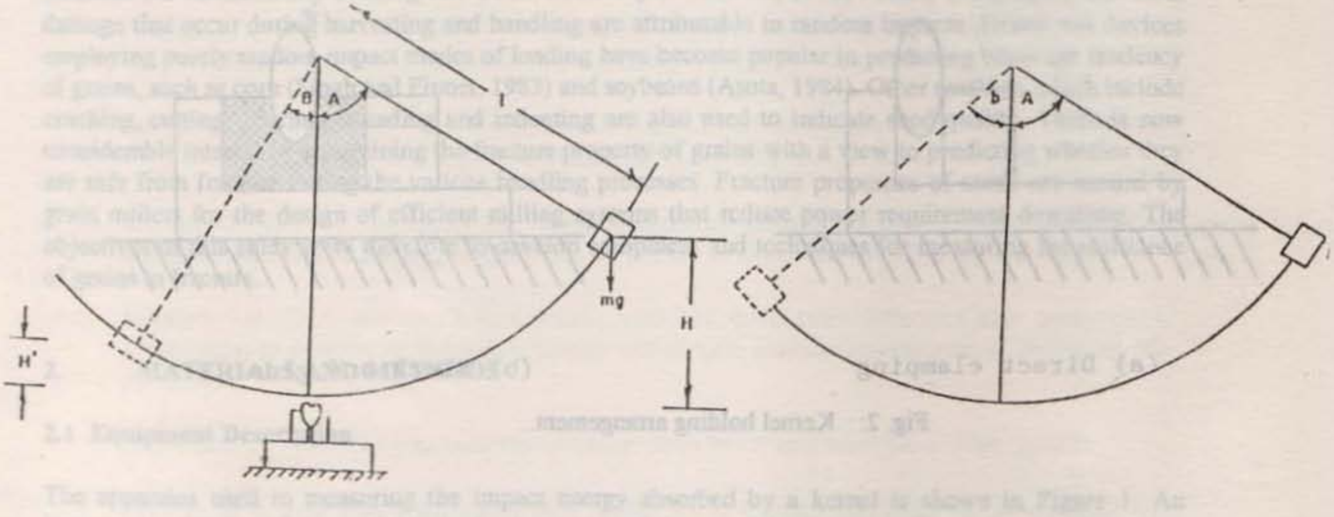

Fig. 3: Space relations for pendulum.

The energy used to shear the specimen is therefore

$$E_S = MLg(\cos B - \cos A)$$

and which can be expressed as a percentage of the initial energy to obtain an index of fracture resistance, F. Thus,

$$F = E_S/E_i = (\cos B - \cos A)/(1 - \cos A)$$

In testing soybeans, an angle of fall of 50^o was found to be adequate for complete shear of the different varieties at moisture levels of 5% -25% (wet basis).

2.2. Experimental Method

Two freshly harvested varieties of soybeans (Corsoy 79 and Hodgson 78) were used to test the sensitivity of the instrument. Kernels were hand-picked from the samples and sorted into two distinct size groups (small and large) according to their diametral dimensions measured with a micrometer. The large size had major and minor diameters of about 7 mm and 4.2 mm respectively while the small size had 4.8 mm and 3.4 mm major and minor diameters respectively. The samples were dried at a low oven temperature of 40°C to about 13% moisture content (wet basis) and subsequently conditioned over saturated salt solution for about 24 hours to allow for equilibration of moisture within each kernel to allow for equilibration of moisture within each kernel before the test. A 2 x 2 x 2 factorial design was employed in testing the sensitivity of the instrument to kernel size and orientation of kernel for impact (Figure 4). The factors, the associated levels and the data are shown in Table 1.

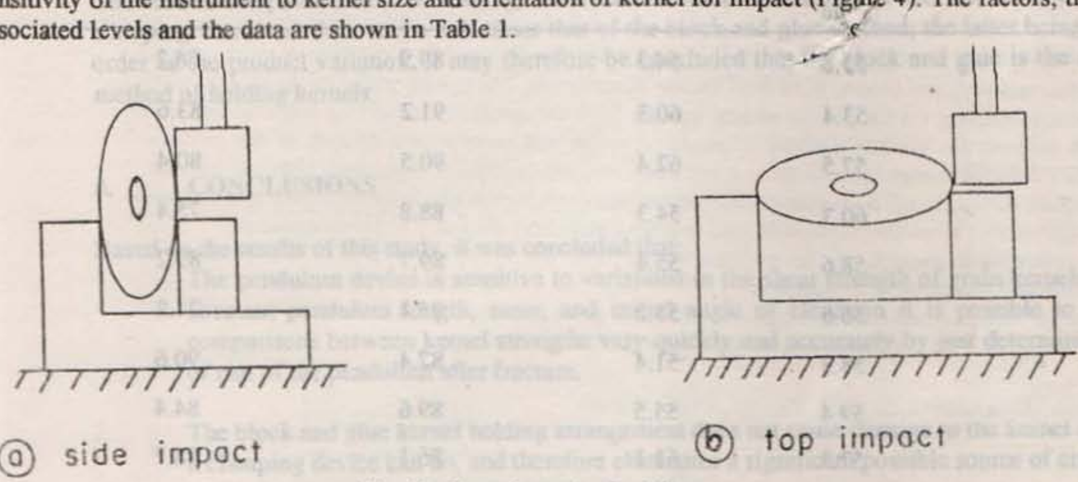

Fig. 41: Bean impact orientations.

TABLE 1:

Shear fracture data and the experimental conditions

Soybean variety	Kernel orientation	Grain size	Fracture Index (%)
Corsoy 79	top	small	87.15
Hodgson 78	top	small	79.58
Corsoy 79	side	small	50.31
Hodgson 78	side	small	60.24
Corsoy 79	top	large	88.99
Hodgson 78	top	large	91.60
Corsoy 79	side	large	30.38
Hodgson 78	side	large	50.31

The block and glue holding method was also compared with the direct clamping method by making 11 consecutive measurements with each method on Hodgson 78 variety (Table 2).

TABLE 2:

Summary of fracture index for the two methods of holding kernel on the vice

	Fracture Index (%)			
	Side orientation		Top orientation	
	Block and glue	Direct clamp	Block and glue	Direct clamp
	55.8	54.3	89.9	78.2
	53.4	60.3	91.2	83.6
	57.5	62.4	90.5	80.4
	60.3	54.3	88.8	75.4
	58.6	55.4	89.7	89.2
	56.6	53.2	85.4	74.8
	58.3	51.4	87.4	90.6
	59.4	55.5	89.6	84.4
	57.3	61.1	86.1	88.7
	61.2	48.7	88.5	91.5
	55.6	56.5	80.2	86.9
Mean	57.7	55.7	87.9	84.0
Variance	5.5	17.4	9.8	36.3

TABLE 3:

Estimated effects from the factorial experiment

Factors	Effects
Variety (V)	6.22
Impact orientation (P)	-39.02
Grain size (S)	-3.75
Interactions:	
V x P	8.71
V X S	5.05
P X S	10.93

3. RESULTS AND DISCUSSION

Analysis of the data indicated that soybeans were less resistant to shear crossways than lengthwise. However the significant interraction which existed between kernel size and the direction of shear were due to the fact that larger sized beans had greater resistance to shear lengthwise, whereas there was no appreciable difference in shear strength between the sizes for the crossways orientations. Furthermore, crossways orientation had lower variability associated with it.

In comparing the two kernel holding arrangements, the approach of variational analysis proposed by Grubbs (1948) was employed to obtain the best estimate of the individual variation of each arrangement. The results computed from the readings from each method indicated that the test variation with direct clamping was about three and a half times that of the block and glue method, the latter being of the same order as the product variation. It may therefore be concluded that the block and glue is the more precise method of holding kernels.

4. CONCLUSIONS

Based on the results of this study, it was concluded that:

1. The pendulum device is sensitive to variations in the shear strength of grain kernels. By using a constant pendulum length, mass, and initial angle of elevation it is possible to make direct comparisons between kernel strengths very quickly and accurately by just determining the angle of rise of the pendulum after fracture.

2. The block and glue kernel holding arrangement does not cause damage to the kernel under test, as a clamping device can do, and therefore eliminates a significant possible source of error.

3. For tests on soybeans, crossways shear is recommended because of the greater sensitivity and lower variability associated with that orientation.

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J. Agric. Engng and Techn. (1994) 2 56-66

AN EVAPORATIVE COOLING SYSTEM FOR RURAL STORAGE OF FRESH TOMATO

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Abstract

A storage system providing high humid environment was designed and constructed with locally available materials and used to store fresh tomato after harvest. The system works on the principles of evaporative cooling via the process of heat transfer from the storage chamber to a wet Hessian sack which encloses the cooling medium. Changes in colour and compressive strength of the produce sampled daily was compared with those stored under ambient conditions. The results obtained with the equipment during the off-harmattan period showed that fresh tomato can store for a period of 30days at a high relative humidity (above 90%) and average temperature drop of 8 ^{0}C below ambient. The compressive strength of the produce stored with the system varied from 0.546N/mm^2 - 0.112N/mm^2 compared to 0.046N/mm^2 - 0.073N/mm^2 for the control within the period of storage. Under the storage condition, ripening of tomato from green to yellow green colour was delayed for 7 days as against 3 days in the case of samples in the control systems.

KEYWORDS: Evaporative cooling, Storage, Fresh tomato.

1. INTRODUCTION

Vegetable production forms 25% of the major food crops grown in the tropics (Eric and Bani, 1988) and so is the means of livelihood for a considerable section of the population. Inspite of their importance in the diet, per capita consumption of vegetables in the developing world is only 100g compared with 200g in the more advanced countries (Grubben, 1977).

In their fresh form, fruits and vegetables are highly perishable after harvest, they tend to shrivel, wither or rot away at very fast rate (Oyeniran, 1986), particularly under hot tropical conditions. The damages that occur in these crops are caused primarily by losses of moisture, change in composition and pathological attack or metabolism.

Some methods of preservation of raw and processed fruits and vegetables include: storage in ventilated shed, storage at low temperatures, use of evaporative coolant system, waxing and chemical treatment. However, refridgerated storage is very popular but it has been observed that several Nigerian fruits and vegetables, e.g. Banana, plantain and mango cannot be stored in the domestic refrigerator for a long period as they are susceptible to chilling injury (NSPRI, 1990). Besides the cost of refrigerators are beyond the reach of low income farmers in the rural communities. To this end it was necessary to develop an effective system for rural storage of fresh fruits and vegetables.

2. MATERIALS AND METHOD

2.1 The Equipment

The assembly and the isometric drawings of the storage equipment used for the experiment is shown in Figures 1 and 2 respectively. It has four basic features - the storage chamber, Hessian sack, water trough and wooden frame.

The frame is made of wood and has four compartments for storage. The storage chamber consists of four trays made of wire netted material with wooden edges and is accessible through a hinged wooden door framework. The entire structure is covered with water absorbing material (Hessian sack) and mounted on a water trough. The sack is made to soak in another water trough placed at the top of the storage structure in

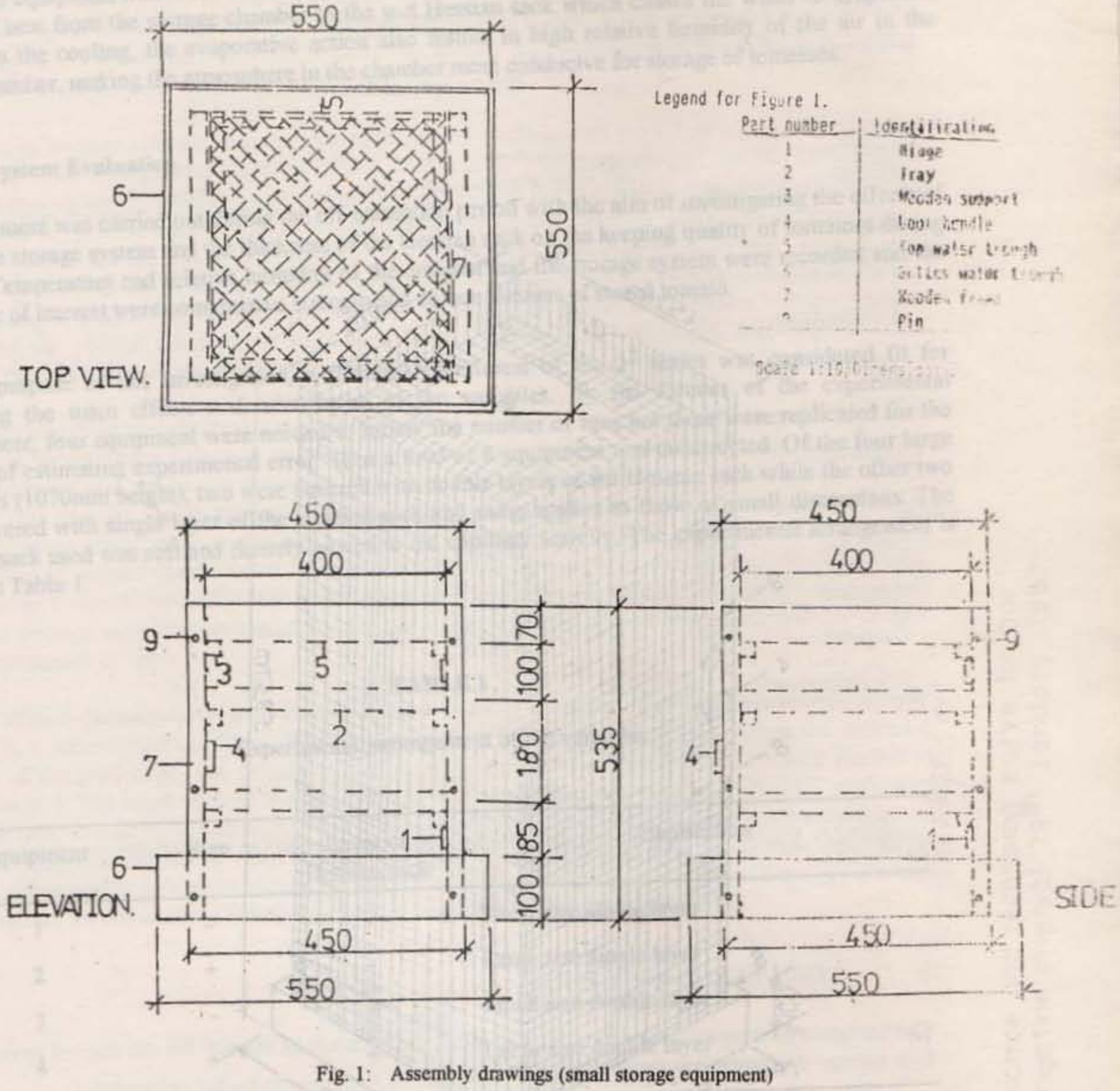

Fig. 1: Assembly drawings (small storage equipment)

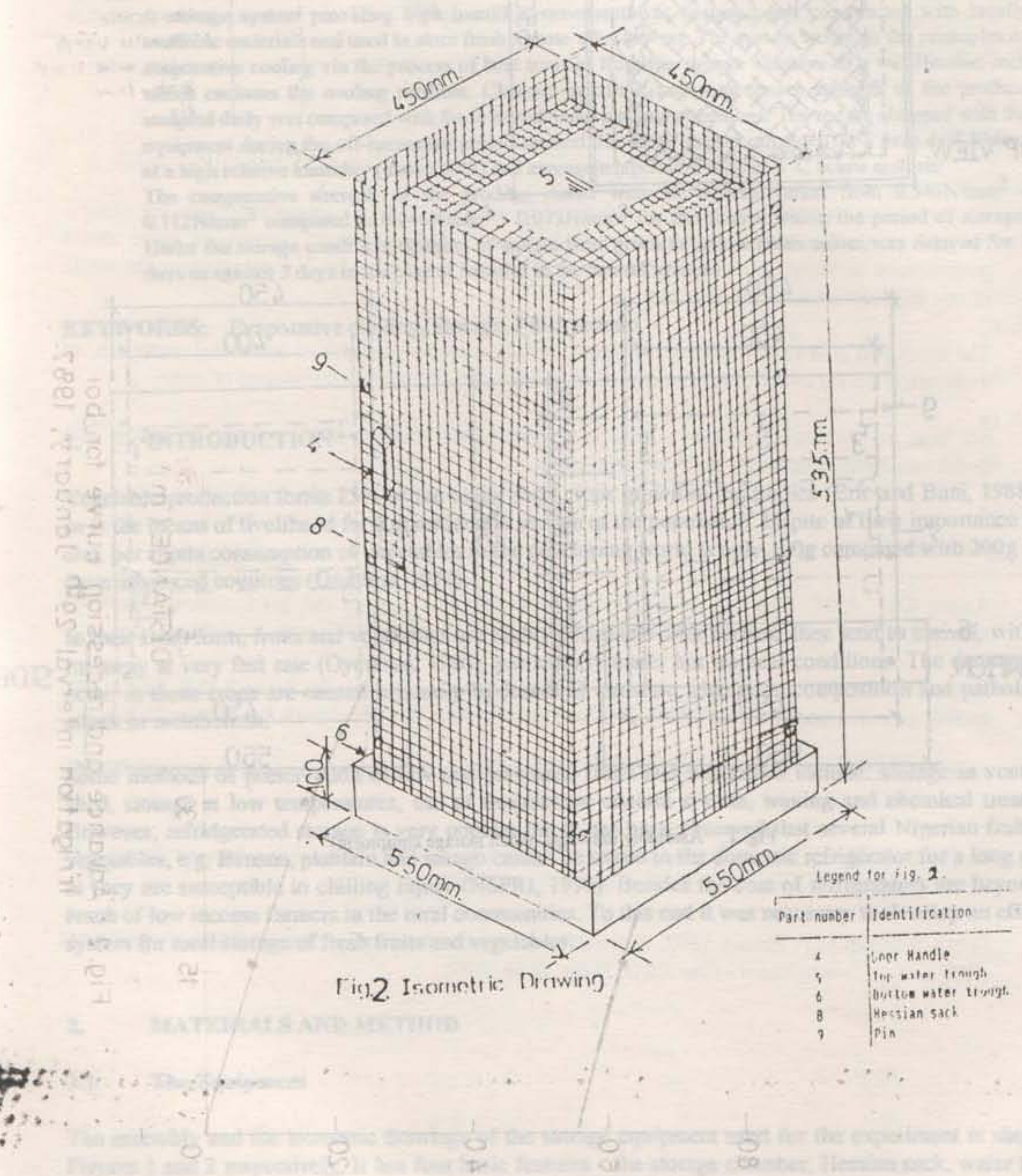

Fig 2: Isometric drawing

order to provide continuous wetting of the Hessian sack by gravity and capillary action. The water troughs are constructed with galvanised steel sheet and coated with emulsion paint to prevent rusting.

The storage equipment thus work on the principles of evaporative cooling. The cooling is provided by the transfer of heat from the storage chamber to the wet Hessian sack which causes the water to evaporate. Apart from the cooling, the evaporative action also results in high relative humidity of the air in the storage chamber, making the atmosphere in the chamber more conducive for storage of tomatoes.

2.2 System Evaluation

An experiment was carried out during the off-harmattan period with the aim of investigating the effects of size of the storage system and the thickness of the Hessian sack on the keeping quality of tomatoes during storage. Temperature and relative humidity of the ambient and the storage system were recorded and the properties of interest were compressive strength and colour changes of stored tomato.

For the purpose of this investigation, a factorial experiment of the 2^2 series was considered fit for estimating the main effects and interaction of the variables. By the dictates of the experimental arrangement, four equipment were needed to satisfy the number of runs but these were replicated for the purpose of estimating experimental error. Thus a total of 8 equipment was constructed. Of the four large size types (1070mm height), two were covered with double layers of the Hessian sack while the other two were covered with single layer of the Hessian sack and same applies to those of small dimensions. The Hessian sack used was soft and densely woven to aid capillary activity. The experimental arrangement is shown in Table 1.

TABLE 1

Experimental arrangement of the variables

Equipment	Size	Layer of Hessian sack	Implication
1	-	-	Small size single layer
2	+	-	Large size single layer
3	-	+	Small size double layer
4	+	+	Large size double layer

Temperature and relative humidity of the ambient and the storage chambers of the equipment were taken three times daily (morning, afternoon and evening). With the measured values of wet and dry bulb thermometers the ambient relative humidity was read directly from the psychrometric chart.

The tomato used for this experiment was of Rome VF variety which is the most available at the time of the experiment. Matured samples of tomatoes were harvested green from the Hayinmalan tomato irrigation plot in Shika, Zaria. The green samples were sorted and stored in each of the storage equipment and in a basket (control). The initial temperature and relative humidity of the chambers and control environment were recorded prior to the introduction of the tomatoes into the storage chambers and the control.

The stored tomatoes were sampled at 2 days intervals, weighed and tested for compressive strength using the Hounsfield tensiometer. Colour changes of the stored tomatoes were determined by observing the stored produce daily and quantified using the colour indices as indicated in Table 2.

TABLE 2

Colour indices for tomatoes

Colour	% Area of colour coverage	Colour code
Green	100	0
Yellow green	<50	1
Yellow green	50-70	2
Yellow green	>70	3
Light red	<50	4
Light red	50-70	5
Light red	>70	6
Deep red	<50	7
Deep red	50-70	8
Deep red	>70	9
Rot Appearance		10

Sampling of stored tomatoes was continued from the green stage to the stage of deterioration.

3. RESULTS AND DISCUSSION

The variation of temperature and relative humidity with period of storage for the control system and the four storage equipment are shown in Figure 3.

The result reveals that the temperature of the storage chamber changes with changes in temperature and relative humidity of the control environment. The average temperature and relative humidity of the control (environment) between the first and the 30th day were 30.9°C and 37.3% respectively while the average temperatures and relative humidities of the four storage equipment a, b, c and d for the same period are 22.2°C and 98.4%; 23.1°C and 97.4%; 23.7°C and 98.6%; 22.5°C and 98.3% respectively. Thus the relative humidities obtained for this equipment conforms with the 98% relative humidity obtained by Adegboyega (1990) for storage of some vegetable produce. The average temperature of the control environment which is considerably higher than those of the storage equipment is an indication of the functional adequacy of the system for storage of produce.

Equipment a and c which are the two smaller equipment maintained slightly higher relative humidities when compared with equipment b and d which have large dimensions. This may be due to the fact that the two smaller storage equipment get saturated with water faster than those of the larger types. From Figure 3 the daily relative humidity of the four storage equipment were nearly constant and close to each other. The

seemingly constant relative humidity when temperature changes in an enclosure separated from the atmosphere by the very pavons hessian sack appear woying (this may be a characteristics of the hessian sack).
The depression in relative humidity and the corresponding rise in the storage temperature of equipment b as indicated in Figure 3 was caused by the cessation of capillary action in that equipment from the 17th day of storage due to the dryness of water in the water trough. The action was restored back by adding sufficient water in the water trough.

The variation of average compressive strength of the stored produce with period of storage for both the control and the four storage equipment are shown in Figure 4. The result reveals that the compressive strength of tomatoes decreases with the storage period. At harvest, the average compressive strength of the tomato samples in both the control and the storage systems is 0.546N/mm^2 and the values decreased over time to 0.073N/mm^2 for the control; 0.143N/mm^2, 0.132N/mm^2; 0.122N/mm^2, 0.112N/mm^2 for a, b, c, d respectively by the 30th day of storage. Tomato samples in the control system experienced rapid decrease in strength than the samples kept in the storage equipment. Thus, the higher temperatures and low relative humidities of the control environment may have been responsible for the rapid deterioration since softening of fruit increases more at high temperatures over 15^0 C (Herregods, 1969).

It was evident also from the results that the storage equipment delayed the ripening (from green to yellow greeen) of the tomatoes for 7 days as against 3 days in the case of the control samples as depicted by Figure 5. The result also shows that the rate of ripening is faster within the control than within the storage equipment. This may be due to higher temperature (above 27^{0}C) of the control environment which is above the optimum temperature range (18-24^{0}C) for the formation of Lycopene, the pigment responsible for red colour of tomato (Sayre *et al*, 1953). Rot was also observed on the samples in the storage equipment after 1 month (30th day) of storage as against 15 days for the control. The comparative colour changes and average compressive strength of tomato samples for the storage equipment and the control system are presented in Table 3.

The high relative humidity produced in the storage chamber maintains the tomatoes in the storage equipment at a more turgid condition, compared with those in the control system, hence the extended storage life of the product as. The calculated effects on the compressive strength of the stored product is shown in Table 4. The result showed that the effect of size was statistically significant at 0.05 confidence level for the first, second, third and fourth weeks. This could be the reason for the good performance of the two storage equipment (a and c). Also, when the calculated effects of thickness of Hessian sack has no significant effect on the storage condition at the first, second, third and fourth weeks. Also, interraction between size and thickness of the Hessian sack in this experiment was not significant.

TABLE 3

Comparative colour changes and average compressive strength of tomato

Colour changes	Duration (days)		Compressive strength (N/mm^2)	
	Equipment	Control	Equipment	Control
Green	1-7	1-3	0.546 - 0.479	0.546 - 0.473
Yellow green	8-11	4-6	0.475 - 0428	0.320 - 0269
Light red	12-15	7-9	0.432 - 0.391	0.269 - 0.218
Deep red	16-29	10-13	0.391 - 0.173	0.167 - 0.147
Rot Appearance	30	15	0.112	0.126 - 0.073

TABLE 4

Calculated effects on compressive strength++

Effect	Estimate + Standard Error			
	1st Week	2nd Week	3rd Week	4th Week
Size(s)	-3.75 + 1.55*	-8.35 ± 3.1*	-9.5 ± 4.2*	-11.8 ± 5.12*
Thickness of Hessian sack (T)	-2.25 ± 1.55n.s	-2.65 ± 3.1n.s	-7 ± 4.2n.s	-8.4 ± 5.12n.s
Interraction (S x T)	0 ± 1.55n.s	-0.35 ± 3.1 n.s	0 ± 4.2n.s	0 ± 5.12n.s

++ mean value of weekly data, * significant, n. s. not significant.

4. CONCLUSION

The post harvest behaviour and quality of tomato when subjected to high humidity environment has been studied. From the results obtained it was quite evident that:

(1) A storage period of over 1 month can be achieved for tomato at an average storage temperature and relative humidity of 22.9°C and 92.2% respectively when the ambient temperature and relative humidity respectively were 30.9°C and 37.3%.

(2) Cooling and humidification efficiencies up to 98% and 95% respectively can be achieved with the storage equipment during the storage period.

(3) Delayed ripening of tomato from green to yellow green colour can be achieved by storage at the above conditions for 7 days as against 3 days with the control system.

(4) In order to maintain a higher relative humidity in the equipment, a height of 535 mm is adequate for quick saturation of the Hessian sack with water.

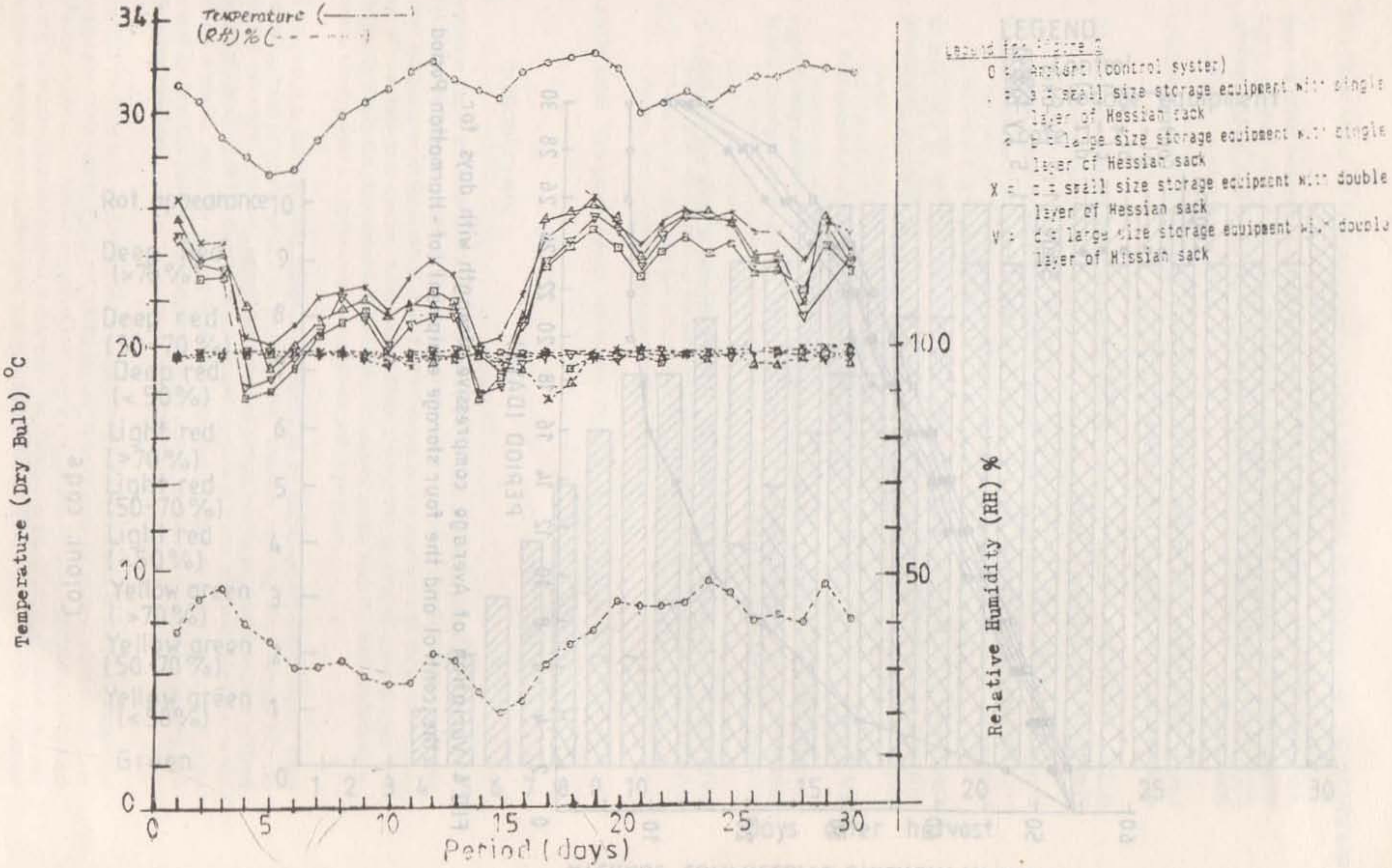

Fig. 3. Variation of Temperature, Relative Humidity responses with days for the control and the four storage equipment.

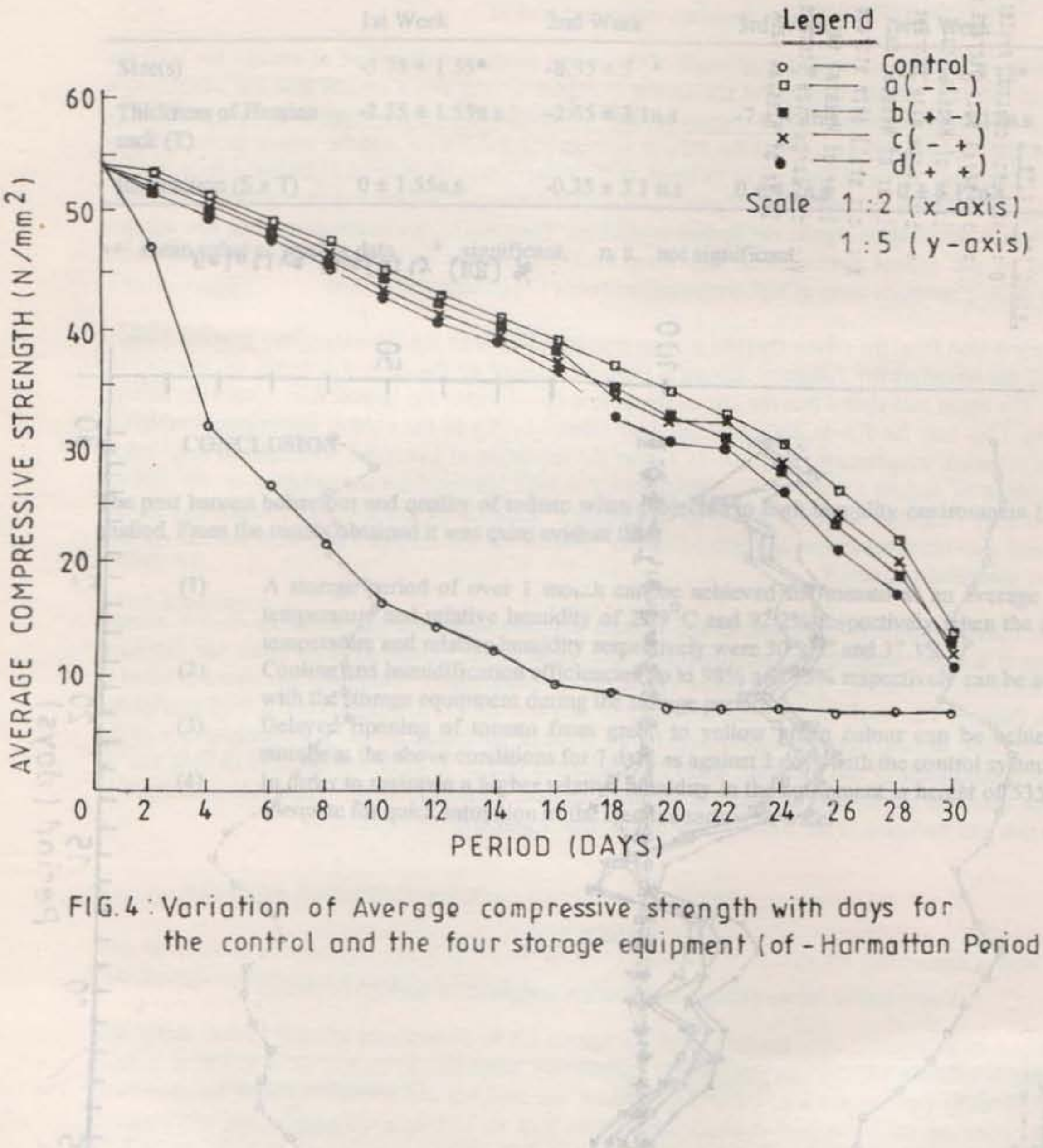

FIG. 4 : Variation of Average compressive strength with days for the control and the four storage equipment (of - Harmattan Period

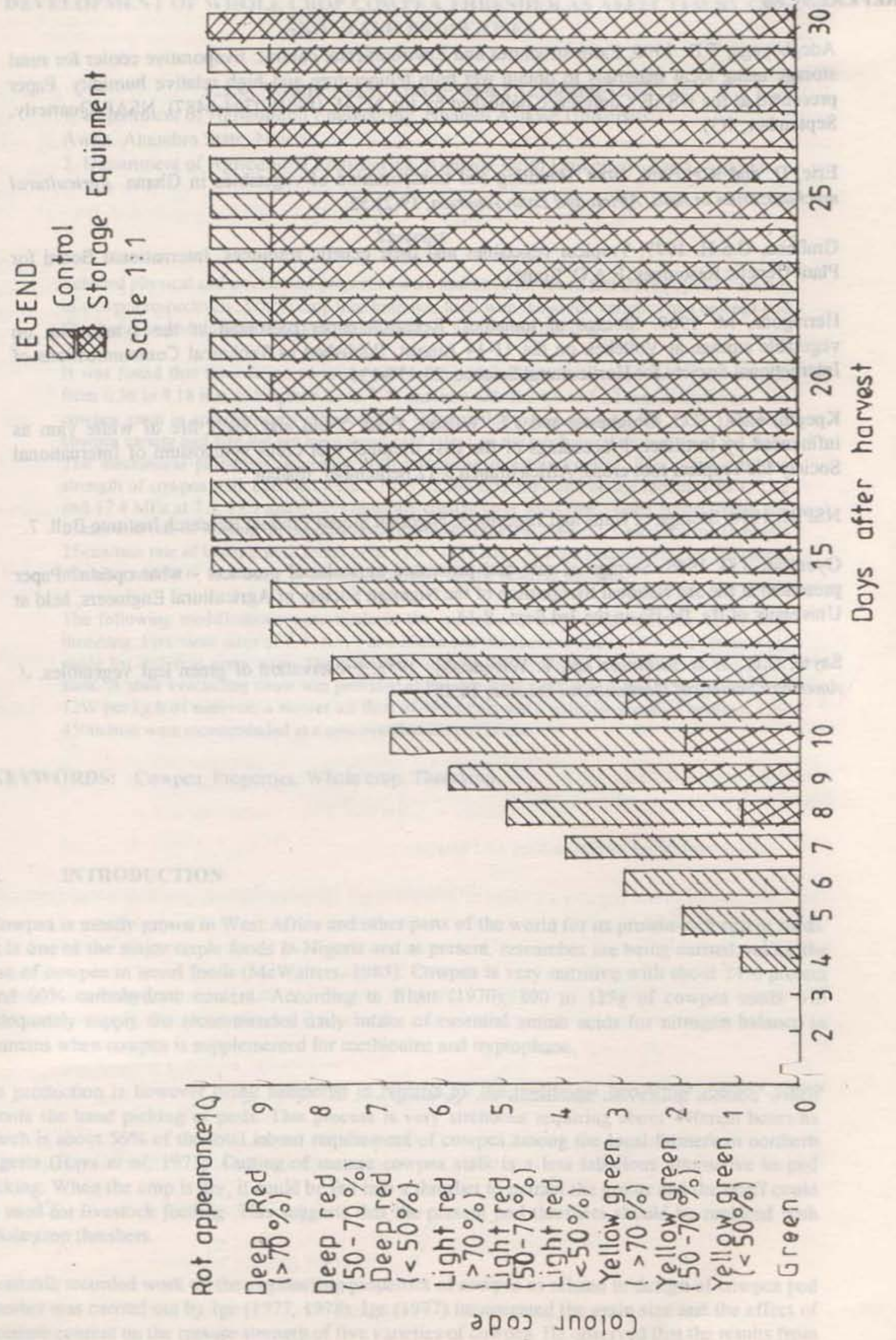

FIG. 5 Variation of colour for Tomato with days after harvest for the control and the storage equipment

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DEVELOPMENT OF WHOLE CROP COWPEA THRESHER AS AFFECTED BY GRAIN AND STALK PROPERTIES

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Abstract

Selected physical and mechanical properties were measured for seven and three popular varieties of cowpea respectively. Whole crop threshing was tried with the seven varieties in a cowpea pod thresher. The pod thresher was then re-designed for whole crop threshing.

It was found that the cowpea varieties differed significantly in their grain size which ranged from 6.36 to 9.18 mm in length, 5.24 to 7.44 mm in width and 4.0 to 5.82 mm in thickness. The cowpea grain is approximately ellipsoidal in shape with a mean sphericity of 78%. However, cowpea variety and size did not have significant effect on the mechanical properties of the stalk. The mechanical properties decreased with increasing moisture content. The mean crushing strength of cowpea stalk obtained were 5.10, 3.67 and 2.59 MPa and elastic modulus 30.4, 23.2 and 17.4 MPa at 7.9, 19.9 and 61.2% moisture content (wet basis (MC) (wb), respectively, and 25mm/min rate of loading. In bending tests, the mean values at 7.88, 22.5 and 70% mc (wb) and 25mm/min rate of loading were found to be 4170, 1273 and 458 MPa respectively, for the elastic modulus and 38.6, 18.8 and 6.17 MPa respectively for the bending strength.

The following modifications were made in the redesign of the pod thresher for whole crop threshing. Five sieve sizes of 7, 8, 8.5, 9 and 10mm and the concave sizes of 8.5 and 10mm were made for different grain sizes. The threshing cylinder was provided with knives to cut fluffy stalk. A stalk evacuating chute was provided at the threshing chamber. A power requirement of 12W per kg/h of material, a blower air flow of 486m/min and a cylinder speed of between 350-450m/min were recommended at a concave clearance of 26mm.

KEYWORDS: Cowpea, Properties, Whole crop, Threshing

1. INTRODUCTION

Cowpea is mostly grown in West Africa and other parts of the world for its protein-rich edible seeds. It is one of the major staple foods in Nigeria and at present, researches are being carried out on the use of cowpea in novel foods (McWatters, 1985). Cowpea is very nutritive with about 24% protein and 60% carbohydrate content. According to Bhatt (1970), 100 to 125g of cowpea seeds will adequately supply the recommended daily intake of essential amino acids for nitrogen balance in humans when cowpea is supplemented for methionine and tryptophane.

Its production is however being hampered in Nigeria by the traditional harvesting method which entails the hand picking of pods. This process is very strenuous requiring about 440man hours/ha which is about 56% of the total labour requirement of cowpea among the local farmers in northern Nigeria (Hays *et al*, 1977). Cutting of mature cowpea stalk is a less laborious alternative to pod picking. When the crop is dry, it could be fed into a thresher to extract the grains and the chaff could be used for livestock feeding. This suggests that the present pod threshers should be replaced with whole crop threshers.

Available recorded work on the engineering properties of cowpea as related to design of cowpea pod thresher was carried out by Ige (1977, 1978). Ige (1977) investigated the grain size and the effect of moisture content on the rupture strength of five varieties of cowpea. He observed that the results from the size measurements could be used to determine the clearance in the threshing chambers, and that the rupture strength was not affected by variety and grain size. Ige (1978) tested a locally constructed cowpea pod thresher with toothed square drum and alternately toothed concave, at six drum speeds and two moisture levels. He found that there was an increase in threshing efficiency and mechanical damage with increase in drum speed.

Dodds (1968) compared the threshing action of spike - tooth and rasp-bar cylinders in self-propelled combine, and concluded that the spike-tooth cylinder had a more positive feeding action and consumed less power than the rasp-bar type. Sharma and Devnani (1980) conducted threshing trials on soyabean and cowpea in rasp cylinder thresher. Using Deshi variety cowpea at 6.5% moisture content, they recommended a concave clearance of 8 mm, and cylinder tip speed of 496 m/min and 288.5 m/min for threshing grains for consumption and seeds for planting respectively.

In a study to develop a thresher with multicrop potential, Singhal and Thierstein (1987) reviewed the thresher accident occurence in India and showed that the spike-tooth thresher was the safest followed by the rasp-bar types out of the five types of thresher studied. Anazodo (1980) and Nwuba (1988) have observed that the failure of crop material in machine cylinder - concave is mainly as a result of bending and compression which result in breaking and crushing of the material. Hence both crushing and bending properties are necessary in the design of a machine to handle such a crop as cowpea.

The objectives of the present study are:

1. To study some physical and mechanical properties of cowpea grain and stalk as related to mechanical whole crop threshing of cowpea.
2. To apply the grain and stalk properties obtained to the re-design of a cowpea pod thresher to make it suitable for threshing the entire crop.

2. MATERIALS AND METHODS

The physical properties of cowpea studied include the grain size and shape, and the moisture content. The mechanical properties of the cowpea stalk in radial compression and simple bending were studied. Whole shoot threshing trials were carried out with a pod thresher which was finally redesigned to effectively handle the entire cowpea crop.

The cowpea varieties used for the tests were grown in the Ahmadu Bello University Farm, in Zaria, Nigeria, under similar environment and agronomical treatments.

2.1 Determination of Grain Size and Shape

The grain size of seven popular varieties of cowpea were measured at between 6 to 7.5% MC (wb) which was the equilibrium moisture content at the period of threshing. One hundred grains were randomly selected from each variety and each grain was measured for the length, width and thickness with 25 mm micrometer screw guage. The average dimension for each variety was then determined. The approximate shape of the cowpea grain was determined by comparion with the existing geometical shapes and the average sphericity was calculated from the measured dimensions of the grain.

2.2 Moisture Content of Grain and Stalk

The moisture content was determined by oven - dry method using American Society of Agricultural Engineers (ASAE) standard. Grains weighing 15g were heated in the oven at $103 \pm 1^{o}C$ for 24 hours.

2.3 Mechanical Properties of Cowpea Stalk

A universal testing machine was used for the measurement of the maximum crushing force (F_c) and deformation (D) in the radial compression tests. The stalk of three varieties of cowpea selected according to grain size, were used for the tests. These are TVX 3236 (length, 6.36mm) Ife brown (7.90mm) and IT 81 D-985 or IT 985 (9.18mm). The specimens were tested at three moisture levels (61.2, 19.9 and 7.9%) and three rates of loading (50, 25 and 12.5mm/min).

In the simple bending tests, the universal testing machine was used to measure the maximum bending force (F_b) and deflection (δ) at three moisture levels and three rates of loading.

2.3.1 Calculation of Mechanical Properties of Stalk

The crushing strain, ε_c, of cowpea stalk in radial compression is given as:

$$\varepsilon_c = D_c/2R = \beta D/100\,(2R) \quad (1)$$

where

D_c = elastic deformation, mm
D = total deformation, mm
R = radius of stalk, mm and
ß = degree of elasticity, %

The formula for calculating the apparent modulus of elasticity, E, of the cowpea stalk in radial compression obtained from Sherif *et al* (1976) is expressed as:

$$E = 4\,F_c Z^2(1 - \mu^2)/\pi Rl \quad (2)$$

and $Z = R/b$ .. (3)

where

F_c = maximum crushing force, N
μ = Poisson's ratio of cowpea stalk in radial compression
l = length of the stalk, mm
b = half the contact width, mm and Z is estimated from

$$\varepsilon_c = (\ln(2z) + \tfrac{1}{2})/2Z^2 \quad (4)$$

The crushing strength, σ_c, is obtained from Hertz equation.

$$s_c = 2F_c/\pi lb \quad (5)$$

In simple bending the cowpea stalk is treated as a beam of annular cross-section simply supported at both ends and loaded at the mid-span.

The bending stress, s_b, is given as

$$\sigma_b = 8F_b ld/p(d^4 - d_o^4) \quad (6)$$

and modulus of elasticity is calculated from

$$E = 4\,F_b\,l^3/3\upsilon_e\pi(d^4 - d_o^4) \quad (7)$$

where

F_b = maximum bending force, N
d = outer diamter of stalk, mm
d_o = inter diameter of stalk, mm and elastic deflection,

$$\upsilon_e = \upsilon_B/100 \quad (8)$$

2.4 Whole Shoot Threshing Trials

2.4.1 Test Thresher

The spike-tooth cowpea pod thresher of the Institute for Agricultural Research (IAR), Zaria, Nigeria, was used for the tests.
The thresher cylinder contained 16mm long, 16mm diameter cylindrical spikes made from hot-rolled steel rods. The cylinder was made up of six spike bars, each containing 16 spikes in two staggered rows of eight per row. The machine was also provided with a blower. Both the blower and the cylinder were provided with 1.49 kW electric motor which transmitted average speeds of 320 rpm and 470rpm to the cylinder and fan spindles respectively, at no load. It was on the bases of its type and performance that the thresher was selected for whole crop threshing trials and subsequent modification.

2.4.2 Test Specimens and Procedure

Whole shoot threshing trials of cowpea were performed using the seven varieties at mean stalk, pod and grain moisture content of 5.45 (S.D. 0.311), 6.91 (S.D. 0.245) and 6.96% (S.D. 0.513) wet basis, respectively.

During the test, 10 kg of material (stalk and pods) were fed gradually into the machine until the grains ceased to drop. The time taken for the operation was recorded with a stopwatch. The weight of threshed grains, chaff in grain, unthreshed grain, damaged grain and the remaining residue in the machine concave were recorded. From these the feed rate, total material output, grain output and % chaff in grain were calculated. A tachometer was used to measure the speed of the threshing and blower spindles.

A germination test was carried out with the threshed grain sample to determine the percentage internal damage. The blower air flow was calculated from blower dimensions using the formulae discussed below.

2.4.3 Calculating of Air Flow Through Thresher Blower

The tangential component of absolute velocity, V_2, can be approximated as 20% of the peripheral velocity of impeller tip (Joshi 1981), hence

$$V_2 = 0.2\pi d_2 N \times 10^{-3} \quad \ldots \quad (9)$$

where

N = impeller speed, rpm and
d_2 = diameter of fan

The theoretical air discharge of the blower, Q_T can be calculated as:

$$Q_T = d_1 w_1 v_1 \times 10^{-6} = d_2 w_2 v_2 \times 10^{-6} \quad \ldots \quad (10)$$

where

Q_T = theoretical air discharge, m^3/min
w_1, w_2 = width of blades (mm) at diameter d_1 and d_2 (mm)
v_1, v_2 = tangential component of absolute velocities, m/min.

Assuming 30% efficiency for blowers (Joshi, 1981) then the actual air discharge, Q_A, is given as:

$$Q_A = 0.3\, Q_T \quad \ldots \quad (11)$$

The air velocity, v (m/min), can be calculated as

$$v = Q_A/wh \times 10^{-6} \quad \ldots \quad (12)$$

where

w = width of air channel, mm and
h = height of air channel, mm

The blower spindle speed was varied by changing the belt pulley diameter until good cleaning was obtained.

3. RESULTS AND DISCUSSION

3.1 Kernel Size and Shape of Cowpea Grain

Table 1 shows the average kernel size measurement for seven varieties of cowpea. The variation in the kernel size was very highly significant (at 0.0001 level). The 95% confidence interval for the mean is also shown in Table 1. *The IT 985 and the local range white varieties which gave the highest* values of interval 9.04 - 9.31 and 8.92 - 9.24mm respectively, were among the largest size of cowpea grains cultivated in the country. It therefore becomes reasonable to limit the thresher concave sieve size to 10mm for the varieties with large grains and 7mm for the varieties with small grains. The clearance between the spikes in the cylinder should be about 12mm to prevent seed damage. The grains of cowpea were found to be approximately ellipsoidal in shape. Holes on the sieves should be elliptical, or for easy construction, circular since the sphericity of cowpea is fairly high (78%).

TABLE 1

Average measurements of kernel size of seven varieties of cowpea.

Variety	Dimensions+ (mm)	Mean	S.D.	Range	95% Conf. Int. for mean
TVX 3236	Length (l)	6.36	0.427	5.50-7.58	6.28-6.45
	Width (w)	5.24	0.327	4.46-6.97	5.18-5.31
	Thickness (t)	4.00	0.254	3.31-4.60	3.95-4.05
Samaru 341	Length	7.69	0.793	6.16-9.92	7.53-7.84
	Width	6.02	0.574	4.81-7.84	5.90-6.13
	Thickness	4.30	0.375	3.24-5.11	4.22-4.37
Ife brown	Length	7.90	0.902	6.38-10.2	7.60-8.10
	Width	6.06	0.462	4.74-7.03	5.97-6.15
	Thickness	4.44	0.381	3.33-5.38	4.30-4.52
IT 60	Length	8.14	0.909	5.29-10.4	7.96-8.32
	Width	6.19	0.568	4.76-7.78	6.08-6.31
	Thickness	4.85	0.407	3.73-5.58	4.76-4.93
Samaru 48	Length	8.49	0.846	7.21-11.7	8.33-8.66
	Width	6.69	0.440	5.75-7.86	6.60-6.77
	Thickness	4.21	0.386	3.34-5.08	4.14-4.29
Local White	Length	9.08	0.806	7.24-11.1	8.92-9.24
	Width	7.44	0.620	5.62-9.06	7.32-7.57
	Thickness	5.82	0.612	4.07-7.22	5.70-5.95
IT 985	Length	9.18	0.698	7.45-10.8	9.04-9.31
	Width	7.39	0.425	5.85-8.58	7.31-7.48
	Thickness	5.42	0.366	4.09-6.25	5.34-5.49

+ Number of measurements per dimension per variety = 100

Sphericity (%) = $100(lwt)^{1/3}/l = 100w/l$ Approx. = 78%

The Duncan's new multiple range test (Table 2) grouped the seven cowpea varieties into five according to their grain size. This grouping aided the selection of the three varieties used for mechanical tests. The table shows that the difference in the sizes in the same grouping. is not significant at 0.05 level which indicates that the same thresher sieves will be adequate for the grains of the same grouping.

TABLE 2

Comparison of the main effect of variety on cowpea kernel size and clogging tendency in 10 min threshing trial+

Variety	Length	Width	Thickness	Time of clogging in 10 min threshing trial, min
TVX 3236	6.36a	5.24a	4.00a	1.67
Samaru 341	7.69b	6.02b	4.30b	2.50
Ife brown	7.90b	6.06bc	4.44c	5.50
IT 60	8.14c	6.19c	4.85d	No clogging
Samaru 48	8.49d	6.69d	4.21b	7.20
Local white	9.08e	7.44e	5.82e	No clogging
IT 985	9.18e	7.39e	5.42e	No clogging

\+ Each value is a mean of 100 measurements.

In each column, mean values with the same letter are not significantly different at 0.05 level as determined by Duncan's new multiple range test.

3.2 Mechanical Properties of Cowpea Stalk

The mechanical properties of cowpea stalk are given in Tables 3 and 4. Two way analyses of variance show that the effect of moisture content on the mechanical properties is highly significant. The mechanical properties increase with decrease in moisture content. Variety and size have no significant effect on the mechanical properties. This means that the same range of power will be adequate for threshing different varieties of cowpea. The relatively high standard deviation observed in the tables is characteristic of such measurements on bio-materials.

The bending trials show that the cowpea stalk broke easily only at low moistures. Whole crop threshing therefore should be carried out at low moisture levels, preferably at 8% (wb) at which the cowpea stalk (as shown in Figure 1) became very brittle.

3.3 The Threshing Trials

The result of the threshing trials with the pod thresher and seven varieties of cowpea is summarized in Table 5.

In summary, the following observations were made:

1. The thresher could basically extract the grains undamaged from the materials,
2. The thresher was too small to handle the entire plant material.

TABLE 3

Mechanical properties of three varieties of cowpea stalk in radial compression at 25 mm/min loading rate and three levels of moisture*

Moisture Content, % (wb)	Variety	Stalk dia, 2R		Crushing force, E_c,N		Crushing strain, E_c		Elastic Modulus, E, MPa		Crushing strength, s_c, MPa	
		Mean	S.D.	Mean	S.D.	Mean	S.D	Mean	S.D	Mean	S.D
61.2	TVX 3236	6.63	1.54	82.7	54.2	0.097	0.015	15.2	4.94	2.54	0.966
	Ife Brown	8.82	1.99	102	36.6	0.079	0.006	19.6	0.70	2.86	0.053
	IT 985	9.47	1.20	82.3	38.7	0.070	0.016	17.3	5.88	2.37	1.13
	Entire pop	8.30	1.88	89	39.2	0.082	0.017	17.4	4.30	2.59	0.774
19.9	TVX 3236	6.60	0.361	125	12.0	0.099	0.016	25.6	4.05	4.24	0.231
	Ife Brown	8.72	0.416	137	10.0	0.087	0.014	24.0	3.33	3.69	0.208
	IT 985	7.53	0.751	97.2	9.57	0.087	0.015	20.0	1.21	3.08	0.232
	Entire pop	7.62	1.03	120	20.1	0.091	0.014	23.2	3.67	3.67	0.537
7.9	TVX 3236	6.48	0.625	194	31.4	0.121	0.012	31.0	6.58	5.84	0.859
	Ife Brown	8.50	0.52	202	74.4	0.098	0.029	31.6	0.819	5.28	1.10
	IT 985	6.28	0.153	103	29.0	0.079	0.005	28.5	6.70	4.17	1.07
	Entire Pop	7.09	1.14	166	63.9	0.099	0.024	30.4	4.93	5.10	1.15

Each value is a mean of three tests. There are nine tests per population.

TABLE 4

Effects of moisture content and rate of loading on mechanical properties of cowpea stalk in simple bending[+]

	Test Date								
	4/11/87			9/11/87			19/11/87		
Stalk moisture content, % wb	70.0			22.5			7.88		
Rate of loading, mm/min	12.5	25	50	12.5	25	50	12.5	25	50
Stalk diameter, d, mm	8.57	9.22	9.91	7.8	8.20	8.50	6.90	6.80	7.55
Hollow pith diameter, d_o, mm	2.02	1.78	1.87	1.75	1.79	1.88	1.75	1.64	1.98
Max. bending force, F_b,N	21.8	38.7	68.0	60.1	75.2	99.0	86.2	105	126
Max. deflection, υ, mm	1.53	1.88	2.44	1.52	1.85	1.75	1.51	2.04	1.00
Degree of elasticity, ß, %		32.9			47.5			62.0	
Elastic modulus, E, MPa	393	458	483	1220	1273	1440	2320	4170	7810
Bending strength, σ_b, MPa	4.26	6.17	8.62	16.4	18.8	21.5	34.1	38.6	37.2

\+ Each value is the mean of three tests. Variety - Ife brown. Loading span = 50 mm.

TABLE 5

The output and efficiency of seven varieties of cowpea in whole shoot threshing trial using IAR cowpea pod thresher+

Variety	Feed rate kg/min	Material output, kg/min	Grain flow, kg/min	% damage		Threshing efficiency, %	% mog* in grain	Concave residue, kg	Remark
				Ext.	Int.				
TVX 3236	0.727	0.355	0.182	0	1	99.5	3.60	3.72	Machine stopped in 1.67 min
Ife Brown	1.03	0.995	0.496	0.152	1	99.6	3.24	0.35	Stopped in 5.5 min
IT 985	1.18	1.14	0.766	0	0	99.2	2.69	0.35	
IT 60	1.14	1.10	0.447	0	1	99.4	2.75	0.36	
Samaru 48	1.02	0.995	0.407	0.241	2	99.0	3.21	0.25	Stopped in 7.2 min.
Samaru 341	0.835	0.471	0.194	0	1	98.6	3.51	3.64	Stopped in 2.50 min
Local white	1.12	1.08	0.434	0	1	99.0	2.75	0.35	
Average	1.01	0.877	0.418	0.056	0.86	99.2	3.12	1.29	Low feed rate to avoid clogging

+ Trial was for 10 min, but was broken in four varieties owing to clogging.
Average drum speed = 250 rpm, 320 rpm at no load
Average fan speed = 400 rpm, 470 rpm, at no load

* Mog = material - other - grain

3. The thresher cylinder required to be redesigned. Since the small stalks could not break, a device for cutting them was essential.
4. There was no way of evacuating the threshing chamber of large broken and crushed stalks except by occasional dismantling which was cumbersome and time-consuming. An evacuating device was necessary.
5. The cleaning system required modification. Table 5 shows that about 3.12% chaff was in the grains. This was too high.
6. Right sieve sizes were not available for various grain sizes tested. It would be necessary to develop five sieve sizes in keeping with the Duncan's new multiple range grading of the grain sizes (Table 2).

The redesign of the pod thresher was based on above observations.

4. REDESIGN OF THE COWPEA POD THRESHER

Based on the results of the trial tests with the IAR pod thresher and the measured properties of cowpea, the following modifications were made in redesigning the thresher:

1. Evacuation chute: A gated stalk evacuation chute of 150 x 420 x 60mm was installed above the chaff chute to evacuate the threshing chamber when necessary with the machine running.
2. Threshing cylinder: The threshing cylinder was redesigned to include eight knives staggered on two opposite threshing bars. The knife angle was made 60^{o} to optimize cutting (Feller, 1959; Prasad and Gupta 1975).
3. Sieves: Two sieves were installed in addition to the concave grate; one at the grain chute and the other on the grain pan. Five sets of sieves with circular holtes 3mm apart, were made for different variety sizes of cowpea in keeping with the Duncan's multiple range test grading of the grain sizes. The sieve sizes were 7mm, 8mm, 8.5mm, 9mm and 10mm. Two sizes of concave grate of circular holes 8.5 and 10mm diameter bored 3mm apart, were provided to suit different varieties of cowpea.
4. Power requirement: The electric motor was changed from 1.49KW to 2.24KW, since a power requirement of 12W per kg/hr of the threshing material was recommended.
5. Cylinder Speed: A cylinder speed of 370 rpm (350m/min) was recommended at a concave clearance of 26mm for threshing grains for general-purpose. When grain were for consumption only, a speed of 475 rpm (35 m /min) was recommended.
6. Blower air velocity: An air velocity of 486m/m in was found to be adequate for cleaning of thresher whole crop.
7. Machine size: The thresher size thus increased to give an overall dimensions of 1500 x 680 x 1440mm after full assembly. The machine is illustrated in Fig. 2. The construction and testing of this machine will be carried out in future studies.

5. CONCLUSIONS

The following conclusions were drawn from the study:

1. Cowpea kernel size is significantly different among different varieties. Of the seven varieties studied, five have grains that are significantly different in size. The mean grain length ranged from 6.35 to 9.18mm; in width, 5.24 to 7.44mm and thickness 4.0 to 5.82mm. Different sieve and concave sizes are therefore necessary for threshing different variety of cowpea.
2. Cowpea grain is roughly ellipsoidal in shape with a fairly high sphericity of 78% Circular holes are therefore appropriate for the sieves and concave.
3. The effect of variety on the mechanical properties of cowpea is not significant. The same range of power will therefore be adequate for threshing different varieties of cowpea.

4. Cowpea stalk has a crushing strength of 5.1 MPa and modulus of elasticity of 30.4 MPa, a bending strength of 38.6 MPa and modulus of elasticity (in bending) of 4170 MPa at 8% mc (wb) and 25mm/min rate of loading.
5. Cowpea stalk is a viscoelastic material since its mechanical properties vary with moisture content and rate of loading.
6. Whole shoot threshing of cowpea is best at low moisture levels when the stalk is brittle.
7. For the spike-tooth thresher at 26mm cylinder-concave clearance, a cylinder speed of 350m/min is recommended for general-purpose threshing, while a faster speed of 450m/min is recommended for threshing grains meant for consumption only.
8. A power requirement of 12W per kg/hr machine capacity is recommended for spike-tooth thresher using only pneumatic separation.
9. An air flow rate of 486m/min was found to be adequate for pneumatic cleaning of threshed whole crop cowpea.
10. A cowpea pod thresher was redesigned to handle the entire crop by the application of the crop properties determined for seven popular varieties of cowpea.

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NOTATION

b	Half width of contact area, mm
d	Diameter, mm
d_1, d_2	Diameter of blower impeller at blade width w_1 and w_2, mm.
d_o	Diameter of hollow pith in stalk, mm
D	Total deformation, mm
D_e	Elastic deformation, mm
E	Elastic modulus, MPa
F_b, F_c	Maximum bending and crushing force, N
Q_A	Actual required air flow rate through the blower, m^3/min
Q_T	Theoretical air flow rate, m^3/min
R	Radius of stalk, mm
t	Thickness of grain
V	Velocity of air, m/min

V_1, V_2	Tangential components of absolute velocities of impeller, m/min
w	width, mm
Z	Term defined as R/b
β	Percent degree of elasticity
ε_c	Crushing strain
μ	Poisson's ration
υ	Maximum deflection in bending, mm
υ_e	Elastic component of deflection, mm
σ_b	Bending strength of stalk MPa
σ_c	Crushing strength of stalk, MPa

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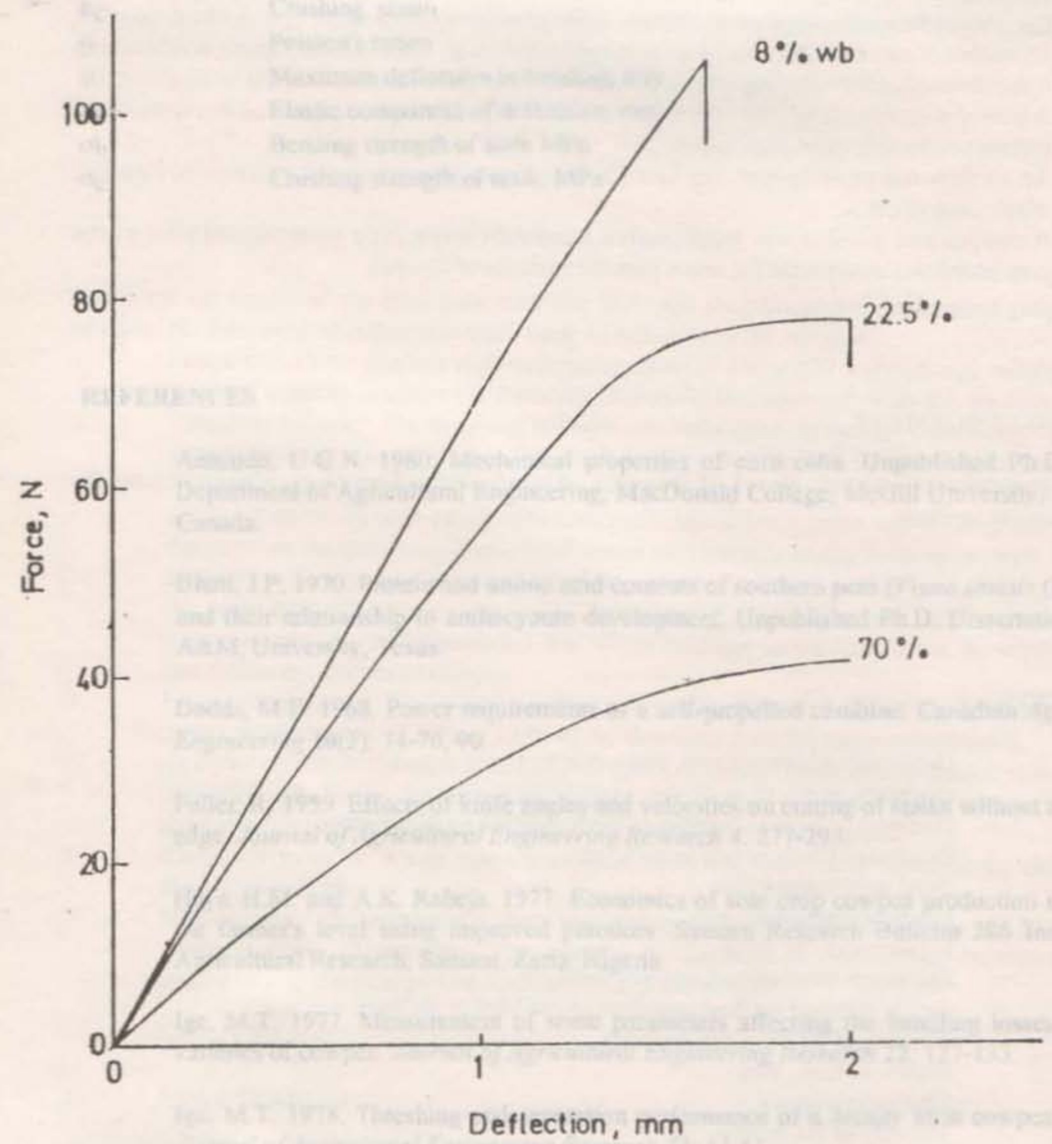

Fig. 1 Typical force-deformation curves of cowpea stalk in simple bending atthree levels of moisture

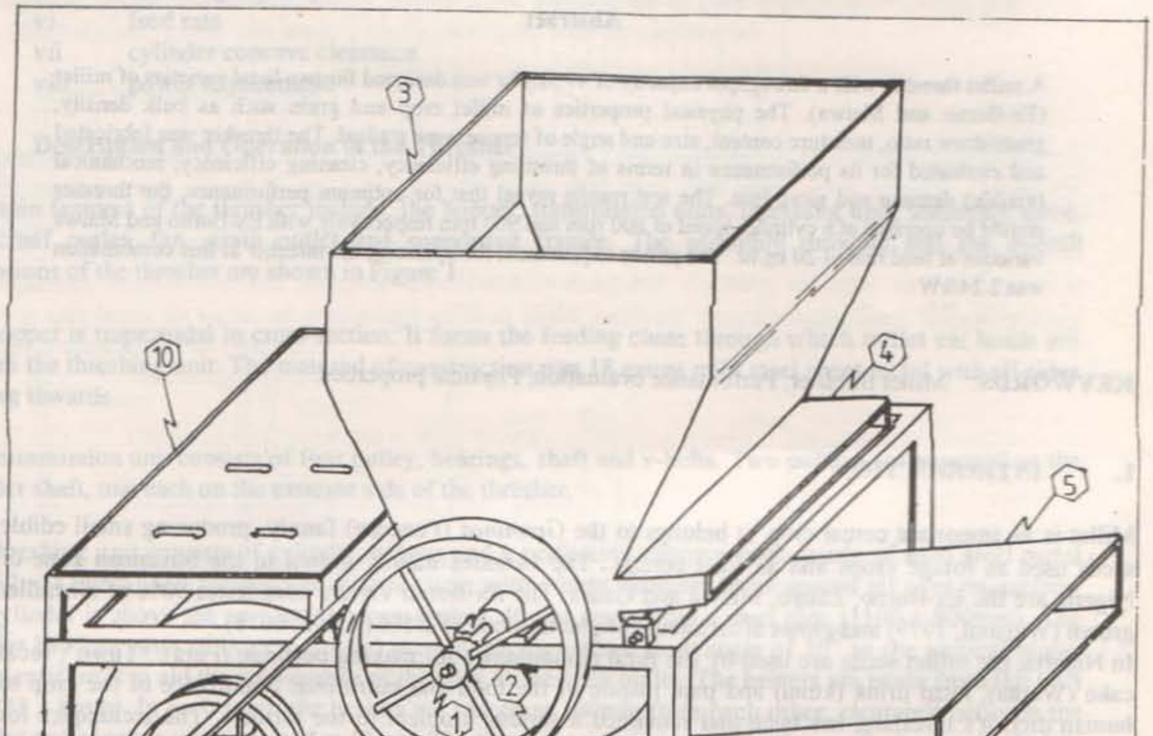

Fig. 2 Cowpea whole shoot thresher

1. Cylinder (drum) shaft
2. Cylinder pulley
3. Hopper
4. Stalk evacuation chute
5. Lower cylinder housing/chaff chute
6. Frame network
7. Grain chute
8. Fan shaft
9. Fan housing
10. Seat for prime mover

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DEVELOPMENT AND PERFORMANCE EVALUATION OF A MILLET THRESHER

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Abstract

A millet thresher with a throughput capacity of 47.5kg/hr was designed for two local varieties of millet (Ex-Borno and Maiwa). The physical properties of millet crop and grain such as bulk density, grain/straw ratio, moisture content, size and angle of repose were studied. The thresher was fabricated and evaluated for its performance in terms of threshing efficiency, cleaning efficiency, mechanical (visible) damage and sieve loss. The test results reveal that for optimum performance, the thresher should be operated at a cylinder speed of 800 rpm and 900 rpm respectively with Ex-Borno and Maiwa varieties at feed rate of 20 kg/hr. The power requirement for operating the thresher at this combination was 2.24 kW.

KEYWORDS: Millet thresher, Perfomance evaluation, Physical properties.

1. INTRODUCTION

Millet is an important cereal crop, it belongs to the *Graminea* (Poaceae) family, producing small edible seeds used as forage crops and as food cereals. The varieties mainly grown in the Savannah zone of Nigeria are the Ex-Borno, Zango, Maiwa and Gaura. The Ex-Borno variety constitutes 90% of all millet grown (Wagami, 1979) and grows at an annual production rate of 2.1% (Abalu, 1978).
In Nigeria, the millet seeds are used by the rural communities for making porridge (Fura), "Tuwo", local cake (Waina), local drink (kunu) and pap. Inspite of the food and nutritional importance of the crop to human diet, it's threshing has been and remained a serious problem to the farmers. The techniques for threshing millet are still by traditional method of seed separation which are uneconomical, laborious and time wasting.

Over the years few multicrop grain threshers have been adapted to thresh millet in Nigeria (Wagami, 1979). These include Alvan Blanch Threshers (midget II and super midget II Thresher) and Garvie midget threshers. However, the performance of these threshers has not been very satisfactory (Choudhury, 1980). It was therefore necessary to design and develop a millet thresher, capable of reducing drudgery, grain damage, grain losses, labour cost, time spent and improving the quality of grain.

Therefore this study was undertaken with the following objectives:

i. To determine some basic physical and engineering properties of two varieties of millet grain (Ex-Borno and Maiwa).
ii. To develop a millet thresher and evaluate it's performance.
iii. To study and recommend the best combination of operating parameters such as cylinder speed, feed rate and crop variety for the capacity and power requirement of the thresher.

The major physical factors limiting the design of millet thresher have been reported by some test reports by Choudhury (1978), Choudhury (1979), Sambaugh (1966), Singhal and Thierstein (1987) and Wagami (1979).

2. MATERIALS AND METHODS

2.1 Design Consideration and Relevant Engineering Properties of the Grain.

Before the design and fabrication of the thresher it was necessary to consider some physical and engineering properties of the millet grain. These include moisture content, bulk density, grain/straw ratio, size and angle of repose. The following design parameters were established after measurement of the physical properties of the millet grain and review of available technical literature.

i length of threshing area.
ii cylinder speed
iii fan speed
iv straw separation length and total separation length
v threshing capacity
vi feed rate
vii cylinder concave clearance
viii power requirement.

2.2 Description and Operation of the Thresher

The main features of the thresher include: the hopper, transmission units, threshing unit, stationary sieve, stalk/chaff outlet, fan, grain outlet and supporting frames. The assembly drawing and the overall dimensions of the thresher are shown in Figure 1.

The hopper is trapezoidal in cross-section. It forms the feeding chute through which millet ear heads are fed into the threshing unit. The material of construction was 18 gauge mild steel sheet metal with all sides slanting inwards.

The transmission unit consists of four pulley, bearings, shaft and v-belts. Two pulleys are mounted on the cylinder shaft, one each on the extreme side of the thresher.

The threshing unit consists of cylinder, beaters and a perforated concave plate, made of mild steel metal (235.62 x 820mm) and formed into a semi-circle with 10mm diameter holes spaced all over its surface. The cylinder is above the perforated concave plate. It was made from a steel pipe (1100 x 800mm). The cylinder has four rows of beaters welded strongly on it's surface at an angle of 30^{0} to the vertical plane, this orientation is to aid the conveyance of the stalk to the stalk outlet. The beaters are made from flat bars *(42 x 22 x 8mm). In each rows, the beaters are spaced at 100mm* from each other, clearance between the cylinder and concave is maintained at 42mm. The threshing unit is covered with a semi circular steel plate *(471.24 x 820mm) to prevent loss of grains through scattering.*

The fan is stationed at a distance of 448mm below the perforated concave directly opposite the chaff outlet to give a winnowing effect. It is an axial flow type with four blades.

A stationary sieve plate constructed with mild steel metal sheet (255 x 250mm) is positioned below the fan with 3 mm diameter holes spaced all over the surface to further grade the grains. Below the sieve plate is the grain outlet.

The structural frame forms the mounting support of all other units of the thresher and is made of 25 x 25mm angle bar. The overall dimension is 905 mm x 1100 mm.

The thresher works on rotary impact principles. The cylinder is designed to rotate at 900rpm during operation, millet ear heads are fed uniformly into the hopper. The earheads fall by gravity on the rotating cylinder *and are threshed by impact of beaters and are whirled round between the perforated concave and the rotating cylinder. The chaff and the grains fall through the* concave openings and are directed to grain outlet by *configuration of casing. Just before falling* on the sieve, the blower air stream blows off the chaff through the chaff outlet leaving behind clean grains. The sieve is manually agitated to further grade the grains before collection at the grain outlet.

2.3 Determination of the Physical and Engineering Properties of the Grain

This study was limited to two varieties of millet (Ex-Borno and Maiwa).

The hardness of the grains was determined for two varieties of millet (Ex-Borno and Maiwa) by measuring the length, diameter, weight and size of the grain. A vernier caliper of 0.01cm calibrations was used for all linear dimensions and a Mettler balance with 0.01grams calibrations was used for all weighings while the

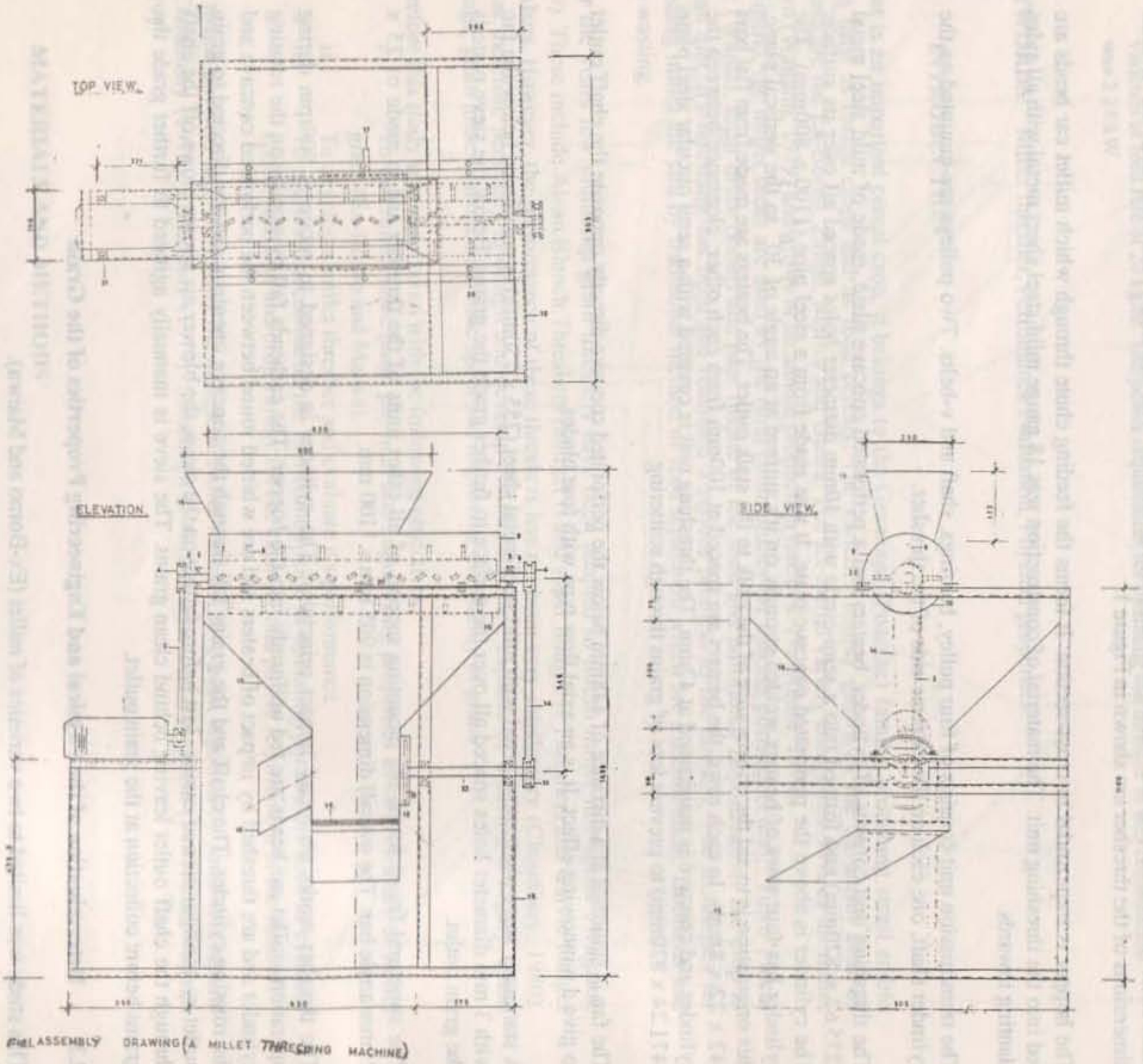

Fig. ASSEMBLY DRAWING (A MILLET THRESHING MACHINE)

Nº OF ITEMS	DESCRIPTION & SPECIFICATION	QTY.	MATERIAL
1	PRIME MOVER (MOTOR) (2 H.P. 1500 RPM)	1	
2	PULLEY A (Ø 50 X 25mm)	1	MILD STEEL (M.S.)
3	BELT A (V-BELT [illegible])	1	LEATHER
4	PULLEY B (Ø 80 X 25mm)	2	M.S.
5	BALLBEARING (SERIES 6205 BORE 25mm [illegible])	4	
6	CYLINDER SHAFT (Ø 25 X 100mm)	2	M.S. ROD
7	CYLINDER (Ø 100 X 800mm HOLLOW PIPE)	1	M.S. PIPE
8	BEATERS (42 X 22 X 8mm BAR)	28	M.S. BAR
9	COVER PLATE (SEMI-CIRCULAR Ø 300 X 820mm)	1	M.S. SHEET (GAUGE 16)
10	PERFORATED CONCAVE (SEMI-CIRCULAR Ø 150 X 820mm)	1	M.S. SHEET (GAUGE 16)
11	PULLEY D (Ø 80 X 25mm)	1	M.S.
12	FAN HOUSING (Ø 200 X 300mm)	1	M.S. SHEET (GAUGE 12)
13	FANBLADE (70 X 30 X 40mm)	4	GAUGE 16 M.S. SHEET
14	BELT B (V-BELT [illegible])	1	LEATHER
15	FRAME (2" X 2" ANGLE BAR)		M.S. ANGLE BAR
16	CHAFF OUTLET (Ø 200 X 253mm)	1	M.S. SHEET 16 GAUGE
17	SIEVE (85 X 255 X 350mm)	1	[illegible]
18	GRAIN OUTLET (Ø 200 X 151mm)		
19	HOPPER (166 X 350 X 71mm X-SECTION AND 350mm LENGTH)		M.S. SHEET 18 GAUGE
20	BOLT (Ø 5mm)	6	M.S.
21	BOLT (Ø 8mm)	4	M.S.
22	BLOWER'S SHAFT (Ø 25 X 371mm)	1	M.S. ROD

SCALE
1 : 7
DIMENSION IN MM

hardness tester of 20kg maximum load with 5mm spindle diameter (Kiya No. 140 type) was used for hardness test.

Moisture content of grain was determined by oven dry method at a temperature of 130^{o}C for 18 hours (ASAE, 1972). A revolution counter (tachometer) was used for speed measurement. All measurements were taken in the laboratory at a room temperature of 29^{o}C and 32% relative humidity.

The angle of repose was determined by allowing the millet grain to flow from a point into a pile. The angle which the side of the pile made with the horizontal was then measured.

2.4 Performance Evaluation

A combination of feed rate, F, at 2 levels (20 and 400kg/hr); crop varieties, V, at 2 levels (Ex-Borno and Maiwa) and cylinder speed, S, at 3 levels (700 rpm, 800 rpm, 900 rpm) were selected. In all 12 combinations of F, V and S were formed with each combination replicated thrice. The threshed materials were collected at the outlets, cleaned and weighed. The portion of the material containing unthreshed grain was separated from straw and weighed after handthreshing and cleaning in order to determine the threshing efficiency in terms of percentage of total grain received. The formular used for calculating different parametersare as follows:

i. Threshing efficiency (%) = $100 - Q_U/Q_T \times 100$ (1)

ii. Cleaning efficiency (%) = $W_T - W_C/W_T \times 100$ (2)

iii. Mechanical (visible) damage (%) = $Q_b/Q_T \times 100$ (3)

iv. Sieve loss (%) = $Q_{FC}/Q_{in} \times 100$ (4)

where

Q_u = quantity of unthreshed grain in sample (g)
Q_T = total grain in sample (g)
W_T = total mixture of grain and chaff received at the main outlet (kg)
W_C = weight of chaff at the main outlet of the thresher (kg)
Q_b = quantity of broken grains in sample (g)
Q_{FC} = free, clean grains collected from sieve sample per unit time.
Q_{in} = total grain input per unit time.

3. RESULTS AND DISCUSSION

3.1 Physical and Engineering Properties of Millet Crop and Grain

Based on the laboratory studies the result of the physical characteristics of different varieties of millet crop; and the physical/engineering properties of different varieties of millet grains respectively are presented in Tables 1 and 2. The grain-straw ratio and the bulk density were used to estimate the theoretical capacity of the thresher. Size of grain was useful in deciding the hole diameter on the sieve used in cleaning and concave.

The length of ear head was used to decide the length of the feeding chute while the angle of repose was used to decide the angle of grain pan and inclination of the feeding chute.

3.2 Threshing Efficiency

Figure 2 shows the effect of cylinder speed, feed rate and crop variety on threshing efficiency. The result reveals that the threshing efficiency increases with an increase in cylinder speed for all feed rates and different crop varieties. The maximum threshing efficiency of 96.8% was obtained at the lowest feed rate

TABLE 1

Physical characteristics of different varieties of millet*

Variety Value	Wt. of earhead (gm)	Length of earhead (cm)	Length of grain portion	Dia. of earhead (cm)			Wt. of grain (gm)	Wt. of chaff/s traw (gm)	Grain/ straw ratio	Grain moisture content (%)
				Top	Middle	Bottom				
Ex-Borno: Average	44.73	35.20	31.61	1.80	2.22	2.12	29.22	15.51	0.65	10
Maximum	69.67	45.00	44.90	2.18	2.66	2.90	47.25	22.42	0.68	10
Minimum	28.88	31.80	31.75	1.56	1.90	1.69	17.62	11.26	0.61	10
X	47.76	37.33	36.09	1.85	2.26	2.24	31.36	16.40	0.65	
V	281.89	31.32	38.84	0.07	0.097	0.25	148.62	21.15	0.00083	
S.D	16.79	5.60	6.23	0.27	0.31	0.5	12.19	4.60	0.029	
Maiwa: Average	58.10	44.30	43.49	1.85	2.08	2.00	40.89	17.21	0.70	9.10
Maximum	68.18	49.50	49.00	2.01	2.25	2.39	46.86	21.32	0.69	9.10
Minimum	35.12	39.10	38.60	1.40	1.78	1.63	24.24	10.88	0.69	9.10
X	53.80	44.30	43.70	1.75	2.04	2.01	37.33	16.47	0.69	
V	191.40	18.03	18.05	0.067	0.039	0.096	91.61	18.44	0.000033	
S.D	13.83	4.246	0.258	0.197	0.310	9.57	4.29	0.0058		

* Average of ten earheads; X = mean; V = Variance, S.D. = Standard deviation.

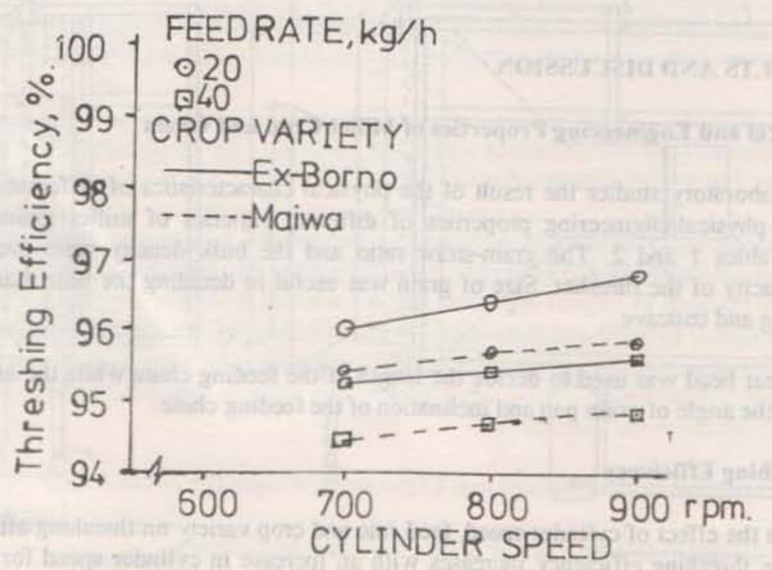

Fig. 2 Effect of cylinder speed, feed rate and crop variety on threshing efficiency

TABLE 2

Physical and engineering properties of different varieties of millet grains

Physical and Engineering properties	Value	Variety: Ex-Borno	Variety: Maiwa
Max. length of grain (mm)	Average	4.00	3.90
	Longest	4.90	4.88
	Shortest	3.39	3.20
	X	4.10	3.99
	V	0.39	0.48
	S.D	0.62	0.69
Max. diameter of grain (mm)	Average	2.00	2.48
	Longest	2.40	3.00
	Smallest.	1.45	2.00
	X	1.95	2.49
	V	0.15	0.17
	S D	0.39	0.41
Weight of grain (gm)	Average	0.017	0.038
	Heaviest	0.029	0.069
	Lightest	0.009	0.02
	X	0.018	0.042
	V	0.000068	0.00041
	S.D	0.0082	0.020
Hardness of grain (kg)	Average	2.00	2.05
	Hardest	4.20	4.50
	Softest	1.10	0.78
	X	2.42	2.44
	V	1.64	2.38
	S.D	1.28	1.54
Bulk density (kg/m^3)	Average	798.00	870.00
	Highest	895.20	924.47
	Lowest	754.00	825.10
	X	815.73	873.19
	V	3480.14	1650.82
	S.D	58.99	40.63
Angle of repose (degree)	Average	13.95	14.00
	Highest	14.10	14.40
	Lowest	13.60	13.80
	X	13.88	14.07
	V	0.044	0.062
	S.D	0.21	0.25
Moisture content (%)		12.0	9.30

X = Mean; V = Variance; S.D. = Standard deviation of 20 kg/hr with Ex-Borno variety at 900 rpm cylinder speed. Minimum threshing efficiency of 94.4% was obtained at lowest cylinder speed of 700 rpm with Maiwa variety of 40kg/hr feed rate. This may be because at a higher speed the energy imparted to the earhed and grain increase causing higher threshing efficiency. The reason for the lower threshing efficiency at higher feedrate with Maiwa variety at lower cylinder speed may be due to the cushioning effect between the cylinder concave clearance and the low impact force at a low cylinder speed.

3.3 Cleaning Efficiency

Figure 3 shows the effect of cylinder speed, feedrate and crop variety on cleaning efficiency. The cleaning efficiency decreases as the feedrate increases for all combinations of feedrate and crop varieties. This may be due to increasing stream of millet ear passing through the cylinder clearance as a result of increased feedrate which burdens the cleaning system. A higher cleaning efficiency was obtained for Ex-Borno than the Maiwa variety for all combinations of feedrate and cylinder speed. This may be attributed to the fact that the chaffs are closely binded to the stock and the grains are more compacted. The fan speed was maintained at 800 rpm. Although better cleaning was observed at higher fan speed but quite a number of grains are blown which result to increased grain losses.

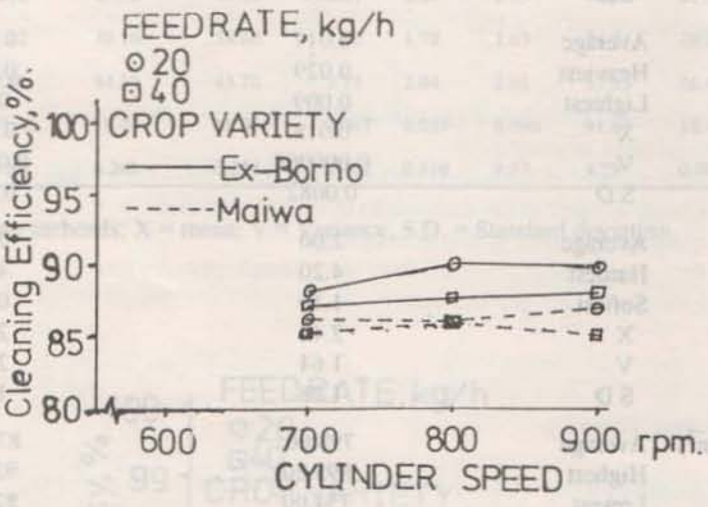

Fig. 3 Effect of cylinder speed, feed rate and crop variety on cleaning efficiency

3.4 Mechanical (Visible) Damage

The effect of cylinder speed, feedrate and crop variety on mechanical damage are presented in Figure 4. It was evident from the figure that with increase in speed, the mechanical damage increased with all combination of feedrate. Also, the percentage mechanical damage ranged between 1.30 to 2.10%. The minimum of 1.30% was at feedrate of 40 kg/hr with ex-Borno variety at 700 rpm cylinder speed while the maximum breakage of 2.10% was at feedrate of 20 kg/hr with Maiwa variety at 900 rpm cylinder speed. This may be due to the reason given in the section above on the characteristics of the two varieties and the operating conditions.

3.5 Sieve Loss

The effect of cylinder speed, feedrate and crop variety on sieve loss are shown in Figure 5. The decrease in sieve loss corresponds to the increase in feedrate with the two varieties of millet grains. The sieve loss varied from 3.5 to 4.5% for different levels of feedrate and the two varieties of millet grains. The

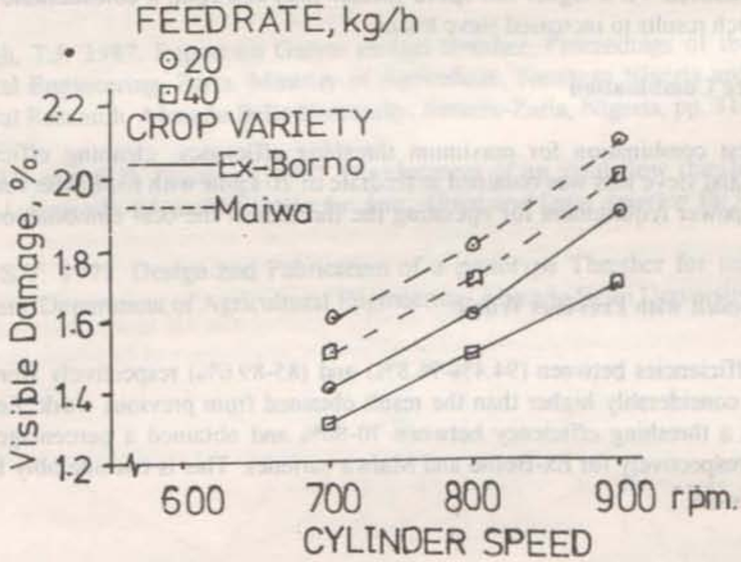

Fig. 4 Effect of cylinder speed, feed rate and crop variety on visible damage

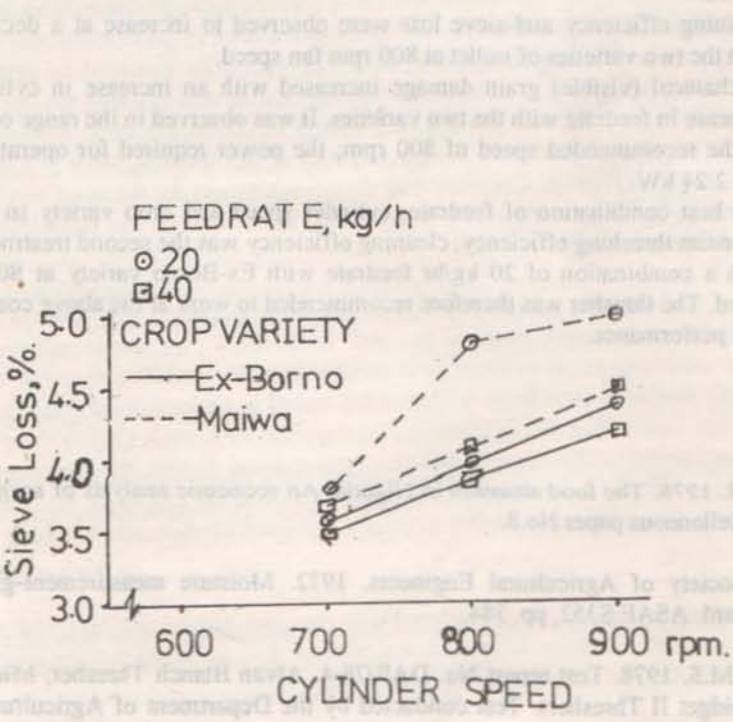

Fig. 5 Effect of cylinder speed, feed rate and crop variety on sieve loss

minimum loss was observed at a feedrate of 40 kg/hr with Ex-Borno variety while the maximum loss was at feedrate of 20 kg/hr with Maiwa variety. This may be because at a lower feedrate, the volume of the material handled by the stationary sieve plate is low as compared to high feedrate. Thus, the material has the tendency to bounce on the sieve and taken out of the sieve plate easily while at high volume of material this action was reduced. At a higher fan speed greater than 800 rpm, a considerable number of grains were blown off which results to increased sieve losses.

3.6 Best Performance Combination

From the results, the best combination for maximum threshing efficiency, cleaning efficiency with minimum visible damage and sieve loss was obtained at feedrate of 20 kg/hr with Ex-Borno variety at 800 rpm cylinder speed. The power requirement for operating the thresher at the best combination was 2.25 kW.

3.7 Comparion of Result with Previous Work

Threshing and cleaning efficiencies between (94.4%-96.8%) and (85-89.6%) respectively were achieved with the thresher. This is considerably higher than the result obtained from previous work. For instance, Wagami (1979) achieved a threshing efficiency between 70-80% and obtained a percentage total loss exceeding 18% and 32% respectively for Ex-Borno and Maiwa varieties. This is considerably higher than the losses obtained in this work.

4. CONCLUSION

A thresher for two varieties of millet has been developed. The following conclusion can be drawn from the experimental results:

i. Threshing efficiency increased with an increase in cylinder speed for all feedrates with the different crop varieties. The threshing efficiency was found in the range of 94.4 to 96.8%.

ii. Cleaning efficiency and sieve loss were observed to increase at a decreasing feedrate with the two varieties of millet at 800 rpm fan speed.

iii. Mechanical (visible) grain damage increased with an increase in cylinder speed and decrease in feedrate with the two varieties. It was observed in the range of 1.30 to 2.10%.

iv. At the recommended speed of 800 rpm; the power required for operating the thresher was 2.24 kW.

v. The best combination of feedrate, cylinder speed and crop variety in order to obtain optimum threshing efficiency, cleaning efficiency was the second treatment combination with a combination of 20 kg/hr feedrate with Ex-Borno variety at 800 rpm cylinder speed. The thresher was therefore recommended to work at the above combination for its best performance.

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PEDAL OPERATED CHIPPING AND SLICING MACHINE FOR TUBERS

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Abstract

A one man pedal-operated machine for chipping and slicing with vertical rotating disc blades and knives respectively was designed, constructed and tested. The machine performance from the tests on yam, cassava, potato and cocoyam showed that it could handle root and tuber crops satisfactorily. Slices of 12.5 mm and 6.25 mm with chips of 2 mm and 1 mm thickness were produced. The maximum throughput capacity obtained was 376 kg/h at an efficiency of 94.1% for 12.5 mm slices while 23.8 kg/h was obtained at an efficiency of 83.4% for 2 mm chips.

Keywords: Chipping, Slicing, Tubers

1. INTRODUCTION

Tuber and root crops occupy the same position in the tropics analogous to grains in the temperate region as the major staple food. The storage potential of the different tuber and root crops vary but generally, they do not store well in the fresh form and transportation is costly due to their bulkiness (Clarke, 1987; Martins, 1972 and Ekechukwu *et al*, 1987).

Processing into staple, non-perishable and easily transportable produce offers an alternative to storage in the fresh form. They are best preserved in the dried form by processing into flour, chips and pellets for both human and livestock consumption. The operation involved in producing these products include washing, peeling, size reduction (chipping, slicing and grating), drying and milling.
Ingram (1972) found out that peeling and slicing of tubers are done manually while Odigbo and Ahmed (1982) reported that there has been efforts at mechanising tuber processing, in the very few processing plants in Nigeria. Chipping and slicing operations are forms of size reduction achieved by cutting, involve pushing and forcing a thin sharp knife through the material resulting in minimum rupture and deformation.

Considering the demand of tuber products for both livestock and human consumption, manual method of processing cannot meet the demand. At the same time, motorised machines cannot be used in the rural areas where the processing is mostly done by unskilled farmers, though several slicing and chipping machines have been designed and tested in various developing countries especially the Carribean and South East Asian countries as reported by Clarke (1987). The Central Tuber Crops Researh Institute (CRCRI), India, and the International Centre for Tropical Agriculture (CIAT) Colombia, in 1983 and 1985 respectively motorised chipping machines for livestock feed production (CIAT, 1985). There are also several manually operated kitchen-size chipping and slicing machines in the market.

This paper describes a pedal-operated machine that can handle chipping and slicing of tubers on a medium scale with emphasis on production of very thin marketable chips (when fried or dried) for human consumption as found in the Nigeria market.

2. DESIGN FEATURES

The machine shown isometrically in Figure 1 has the following major components.

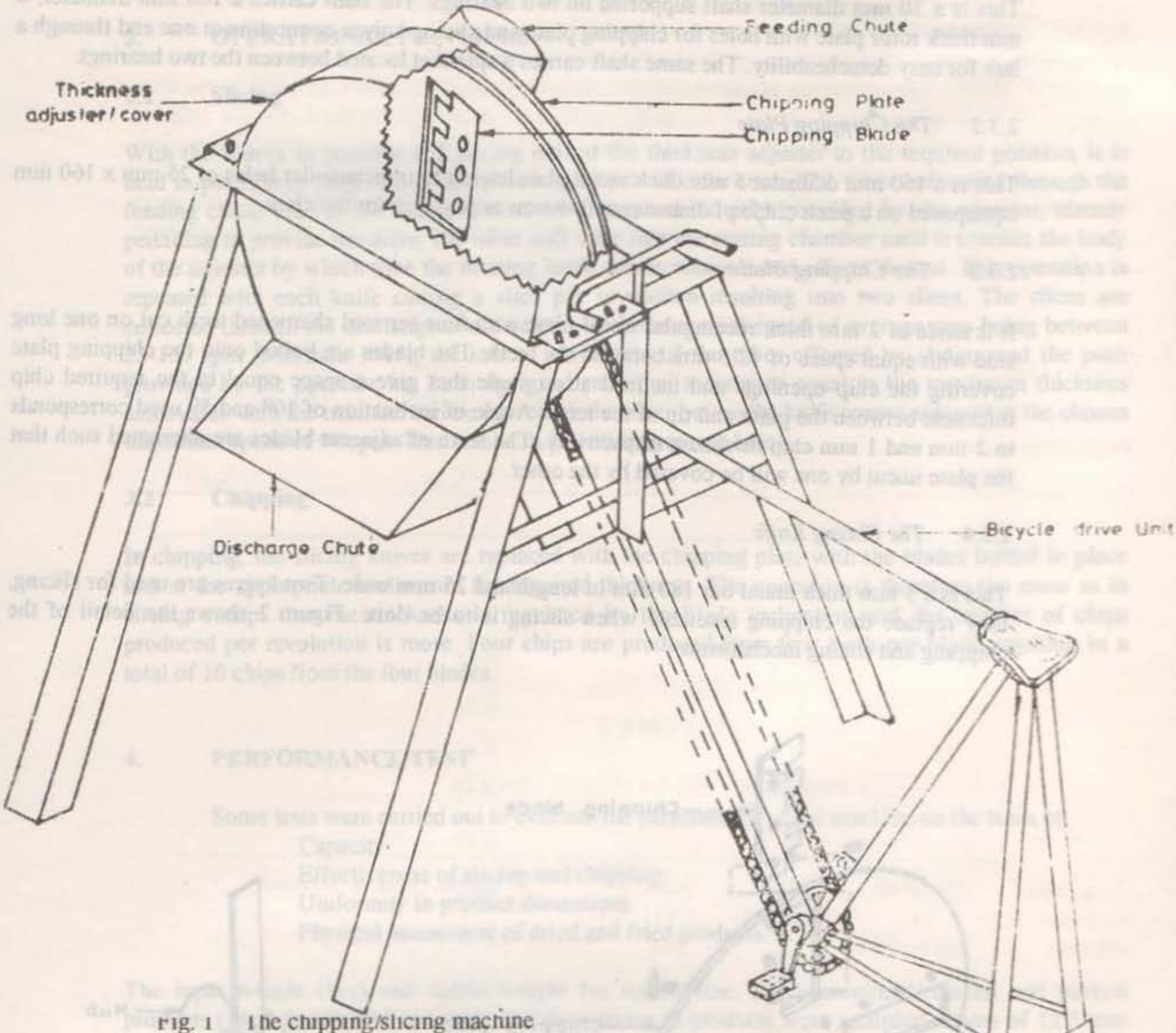

Fig. 1 The chipping/slicing machine

2.1 The Main Frame

This is constructed with 50 mm angle iron bar forming the four 1000 mm long stand each inclined at 60^{o} to the vertical. It provides support to the other units.

2.2 The Operator's Unit

This is a complete bicycle unit excluding the two wheels. It is supported on two angle iron bar legs at the back and connected to the main frame in the front.

2.3 The Cutting Unit

This unit consists of the following parts:

2.3.1 *The Rotor Assembly*

This is a 30 mm diameter shaft supported on two bearings. The shaft carries a 100 mm diameter, 6 mm thick rotor plate with holes for chipping plate and slicing knives connection at one end through a hub for easy detacheability. The same shaft carries a sprocket located between the two bearings.

2.3.2 *The Chipping Plate*

This is a 450 mm diameter 5 mm thick metal plate having four rectangular holes of 25 mm x 160 mm equispaced on a pitch circle of diameter of 360 mm as passages for the chips.

2.3.3 *The Chipping Blade*

It is made of 2 mm thick rectangular metal plate with four serrated sharpened teeth cut on one long side with equal space of 12.5 mm between the teeth. The blades are bolted onto the chipping plate covering the chip openings and inclined at an angle that give a space equal to the required chip thickness between the plate and tip of the teeth. Angle of inclination of 10^{0} and 5^{0} used corresponds to 2 mm and 1 mm chip thickness respectively. The teeth of adjacent blades are alternated such that the plate uncut by one will be covered by the other.

2.3.4 *The Slicing Knife*

This is a 3 mm thick metal bar 180 mm in length and 25 mm wide. Two knives are used for slicing, they replace the chipping assembly when slicing is to be done. Figure 2 shows the detail of the chipping and slicing mechanisms.

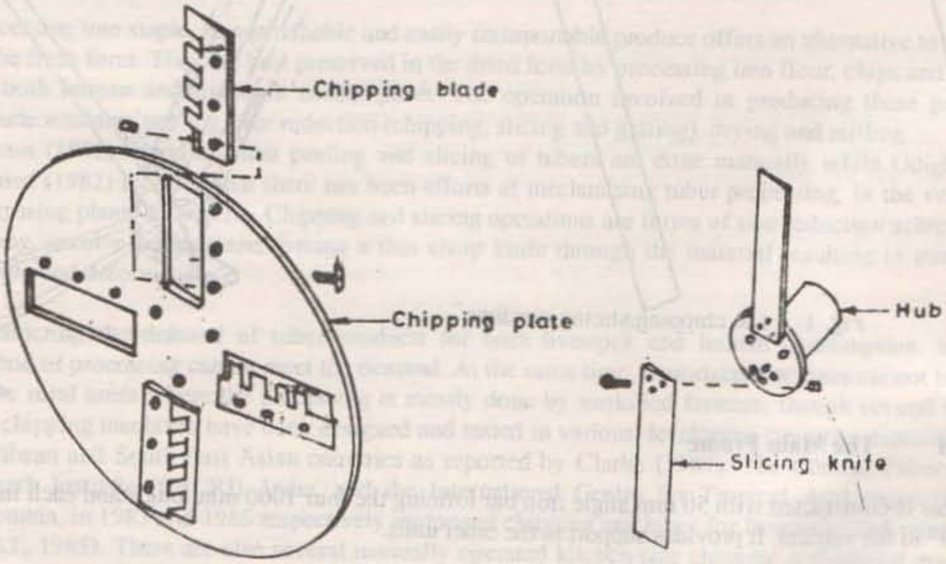

Fig. 2 The cutting mechanisms (a) chipping (b) slicing

2.3.5 *The Housing Cover*

It is made up of two parts, the lower part servicing as the discharge chute and the upper part, carrying the feeding chute which is an inclined cylinder attached to the upper back cover and opens into the cutting chamber. The front serves as the thickness adjuster for slices.

2.4 The Drive Unit

The drive is through sprocket and chain

3. OPERATIONAL PRINCIPLE

3.1 Slicing

With the knives in position and having moved the thickness adjuster to the required position, it is held in position by stop rods inserted into holes provided for such. The tuber is inserted through the feeding chute. Due to the inclination of the chute, and the push provided by the operator, already pedalling to provide the drive, the tuber will slide into the cutting chamber until it touches the body of the adjuster by which time the rotating knife comes across it and effects the cut. This operation is repeated with each knife cutting a slice per revolution resulting into two slices. The slices are collected through the discharge chute below. With the normal speed of average man being between 25-150 rpm (Makinde 1985), the rate of movement of the tuber effected by sliding and the push provided by the operator has been designed such that a distance equal to the maximum thickness achievable with the machine can be moved by the tuber before the knife comes across it at the chosen maximum speed of 90 rpm. This results in 190 slices per revolution.

3.2 Chipping

In chipping, the slicing knives are replaced with the chipping plate with the blades bolted in place and at the appropriate inclination for required thickness. The operation is therefore the same as in slicing except that the thickness is regulated by the blade inclination and the number of chips produced per revolution is more. Four chips are produced from four teeth per blade resulting in a total of 16 chips from the four blades.

4. PERFORMANCE TEST

Some tests were carried out to evaluate the performance of the machine on the basis of:

- Capacity
- Effectiveness of slicing and chipping
- Uniformity in product dimensions
- Physical assessment of dried and fried products.

The input weight (W_1) and output weight for normal/fine, (W_2), abnormal/crushed and broken products (W_3), duration of operation and dimensions of products were recorded. Slices of 12.5 mm and 6.25 mm with chips of 2 mm and 1 mm thickness were produced from four different tuber crops viz: yam, cassava, potato, and cocoyam at different moisture content.

5. ANALYSIS AND DISCUSSION OF RESULTS

The performance data of the machine are as presented in Tables 1 and 2 along with the capacity and efficiency obtained. The capacity was calculated as W_1/T in kg/h while the efficiency was calculated as W_2/W_1.

In Table 1, the results showed that highest capacity of 375 kg/h was obtained during slicing of yam due to its high moisture content. On the other hand, lower performance was obtained with the hard (low moisture) cassava which showed high resistance to cutting *i.e.* high shear strength.

The trend is the same as in slicing in chipping operations (Table 2). The efficiencies of operation are high in all the tubers indicating that little losses are incurred in both in slicing and chipping. Lower

TABLE 1

Performance data for slicing operation

Crop (with moisture content) % w.b.	Duration of operation	Slice thickness (mm)	Input (W_1) (kg)	Weight capacity efficiency			
				Fine (W_2) kg	Abnormal (W_3)	Kg/h	%
Yam (85)	6	12.5	0.626	0.589	0.037	376	94.1
	6	6.25	0.285	0.265	0.020	171	93.0
Cassava (58)	6	12.5	0.501	0.483	0.018	300	96.4
	6	6.25	0.250	0.237	0.013	150	94.8
Potato (78)	-	6.25	0.127	0.118	0.009	-	92.9
Cocoyam (85)	-	6.25	0.191	0.180	0.011	-	94.2

TABLE 2

Performance data for chipping operation

Crop (with moisture content) % w.b.	Duration of operation	Chip thickness mm	Input (W_1) (kg)	Weight capacity efficiency			
				Fine (W_2) kg	Abnormal (W_3)	Capacity	Efficiency
Yam	13	2	0.071	0.055	0.016	19.6	77.5
	15	2	0.091	0.072	0.018	21.6	79.1
Cassava (65)	8.5	2	0.045	0.038	0.007	18.9	84.4
	10	2	0.066	0.057	0.009	23.8	83.4
Potato (75)	10	2	0.064	0.056	0.008	23.0	87.5
Cocoyam (83)	10	1	0.074	0.064	0.010	26.6	86.5

efficiency was obtained in chipping operation, due to the serrated nature of the blade resulting in more contour hence more scrapping, increasing the abnormal products than in slicing.

The dimensions of fifteen representative samples from each test are presented in Tables 3, 4, 5 and 6. To assess the products for uniformity, the Student t-test was used. The level of significance and deviation from the expected dimensions were determined by comparing the t-values obtained for each set of samples with the expected t-value obtained from the statistical table for the number of samples and 1% level of significance which is $-2.624 < t < 2.624$. If the t-value of -5.79 while in chipping, differences were obtained in Potato and Cassava thickness and Potato width with t-value of -3.61 and -2.6 respectively. The reason for these are not unconnected with the low m.c. of the products with small size of the potato making it difficult to be held in the feeding chute. The slices produced are smooth and circular while chips are smooth, uniform and rectangular in shape.

TABLE 3

Slice thickness* obtained for 12.5 mm slicing

	Yam	Cassava
	11.0	11.0
	13.0	10.0
	12.0	12.0
	14.0	11.6
	12.0	10.5
	14.0	11.3
	13.0	13.0
	14.0	11.0
	12.0	12.0
	10.0	11.0
	11.0	10.5
	12.0	9.0
	9.5	11.0
	9.5	12.0
	14.0	10.0
Mean	12.1	11.1
S.D.	1.6	1.0
t	-1.1	-5.8

* All dimensions in mm

The chips were dried in the oven, sun dried in the open air and fried in vegetable oil. The oven dried samples were found to be fully dried in less than an hour while those sun dried in the open air were ready in less than two days. The fried samples on the other hand were ready in less than two minutes. The resulting chips compared favourably with the chips available in the market in terms of shapes and dimensions.

TABLE 4

Slice thickness* obtained in 6.25 mm slicing

	Yam	Cassava	Potato	Cocoyam
	5.0	6.0	7.7	7.7
	5.5	6.2	8.6	6.5
	3.5	8.0	7.5	8.0
	6.5	7.0	9.0	6.0
	6.5	7.1	7.5	3.5
	6.0	7.0	6.5	4.0
	8.0	8.0	6.5	3.5
	7.0	6.0	3.5	5.0
	4.5	5.0	3.7	5.0
	6.0	3.5	6.5	6.6
	4.5	4.0	7.0	5.9
	7.0	4.5	6.0	4.5
	8.0	5.0	6.5	7.5
	6.0	4.5	6.0	7.5
	6.5	6.7	6.5	6.0
Mean	6.1	5.9	6.6	5.3
S.D.	1.2	1.4	1.5	1.5
t	0.6	-1.0	0.9	-2.3

* All dimensions in mm.

TABLE 5

Chip dimensions* length (L), width (W), thickness (T) for 2 mm chipping

	Yam			Cassava			Potato		
	L	W	T	L	W	T	L	W	T
	60	14	2.0	60	14	1.8	48	15	2.0
	55	13	1.7	71	12	2.0	50	15	1.8
	60	14	2.0	75	13	1.9	48	15	1.9
	58	14	1.8	61	14	1.8	50	15	2.0
	57	13	2.0	65	13	1.9	53	15	1.9
	59	13	1.3	55	14	1.8	50	14	2.0
	55	13	1.3	49	12	2.0	48	14	2.0
	57	13	1.3	59	12	1.6	50	14	1.3
	58	12	2.1	70	14	1.5	35	11	1.3
	60	12	2.0	69	13	1.4	50	15	1.8
	55	12	1.8	60	14	1.7	50	12	1.5
	54	13	2.1	55	13	1.9	50	15	2.0
	56	11	1.9	56	12	2.0	52	15	1.4
	60	12	2.0	53	12	2.1	48	13	1.2
	58	13	1.9	48	11	1.9	50	14	1.9
Mean	-	12.8	1.9	-	12.9	1.8	-	14.1	1.7
S.D.	-	0.8	0.1	-	1.0	0.2	-	1.2	0.3
t	-	1.4	-2.5	-	1.5	3.9	-	5.3	-3.6

* All dimensions in mm

TABLE 6

Chip dimensions* length (L), width (W), thickness (T) for1 mm chipping

	Yam			Cassava			Cocoyam		
	L	W	T	L	W	T	L	W	T
	59	12.5	1.1	60	12.0	1.2	60	12.5	0.8
	50	12.5	1.5	40	12.0	1.1	55	13.0	0.8
	55	12.5	1.3	52	13.0	1.0	80	12.5	1.2
	55	12.5	1.2	70	14.0	1.1	70	14.0	1.6
	60	13.0	0.8	75	13.0	1.5	80	11.0	1.0
	49	13.0	1.0	50	14.0	1.0	60	12.5	1.8
	55	14.0	1.1	56	14.0	1.1	71	10.0	1.1
	55	12.5	1.0	45	13.0	1.2	65	13.0	1.1
	56	12.5	1.1	60	14.0	1.1	75	15.0	1.2
	60	13.0	1.1	70	12.5	1.5	58	15.0	1.4
	59	13.0	0.9	50	12.1	1.0	80	14.0	1.0
	60	13.0	1.0	65	12.0	1.0	64	13.0	1.0
	58	12.0	1.1	55	13.0	1.2	35	14.0	1.1
	55	12.0	1.0	49	12.3	0.9	80	12.5	1.5
	60	12.0	0.9	50	11.0	1.1	70	12.5	1.0
Mean	-	12.7	1.1	-	12.8	1.1	-	13.0	1.2
S.D.	-	0.5	0.2	-	0.9	0.2	-	1.3	0.3
t	-	1.3	1.6	-	1.3	3.4	-	1.3	2.4

* All dimensions in mm.

6. CONCLUSIONS

Based on the results obtained from the tests, the following conclusions can be drawn.

- The machine performed satisfactorily with production of chips and slices of uniform thickness ranging from 1 mm to 13 mm which are acceptable and suitable for both human and livestock consumption.
- The machine handled chipping and slicing of available tuber crops satisfactorily.
- A thoroughput capacity of 376 kg/h at an efficiency of 94% was obtained for slicing while 23 kg/h was obtained for chipping at an efficiency of 83%.
- The machine is therefore a good substitute for the low capacity *manual (hand) type*, and the motorised type which required electricity and special skill for operation.

NOTATION

W_1 - Input weight, kg
W_2 - Output weight for fine product, kg
W_3 - Output weight for crushed/broken product, kg
T - Time, s
t - Statistical student-t.

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Books:
Ajibola, O. 1992. NSAE Book of Abstracts. NSAE Publishers. Oba, Abakaliki, Nigeria.

Book Chapter
Mohammed, S. J.H. Musa and P.I. Okonkwo. Ergonomics of Referencing. In: E.I.U. Nwuba (Editor). Ergonomic of Farm Tools. Ebonyi Publishing Company. Osogbo, Oshun State, Nigeria.

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