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REVIEW PAPER

PROBLEMS OF APPLICATION OF MODERN BIOTECHNOLOGY IN AGRICULTURE IN DEVELOPING COUNTRIES

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ABSTRACT

Three broad fields of agriculture in which application of biotechnology is relevant are crop production, livestock production and food processing. The biotechnological techniques in crop production include tissue culture, microbial inoculation of plants, and plant genetic engineering. Of all these techniques, microbial inoculation of plants is the one whose prospects for improved agriculture in developing countries are very good. The other techniques are labour intensive, time consuming and extremely costly to operate. Production of high yielding varieties (HYVs) through genetic engineering in particular, demands a lot from the environment and does not always ensure sustainability. Biotechnological techniques in livestock production such as bioconversion of lignocellulosic wastes, rDNA technology, embryo technology and animal genetic engineering are not popular in developing countries because of unresolved technical problems as well as high cost of operation. In the field of food processing, fermentation technology is discussed as it applies to production of food and beverages in various parts of the developing world. The processes involved in the making of some modern and indigenous fermented foods and alcoholic beverages suggests a need for improvements of the technologies in other to make such products comparable to what obtains in the developed countries. The need to conduct more research into the advancement of indigenous fermentation technology so as to improve the quality and increase the shelf lives of the products remain a *sin qua non* for their acceptability. Also, biotechnology as it is currently being applied in the area of food production is seen as a venture that has failed to solve the problem of hunger in developing countries. Genetically engineered cropping systems are condemned for not being based on ecologically sound agroecological farming principles. There is need for developing countries to identify specific areas of agricultural development for which affordable and readily available biotechnological principles could be applied as to ensure sustainable development.

KEYWORDS

Agriculture, Biotechnology application, Problems

1. INTRODUCTION

Biotechnology is simply defined as the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services. As a discipline, biotechnology implies the use of microbial, animal or plant cells or enzymes to synthesize, break down or transform materials (Lubberding, 1990). This requires the integration of biochemistry, biology, microbiology, chemical engineering, process engineering, together with other disciplines (Fig 1) in a way that optimises the exploitation of their potentials.

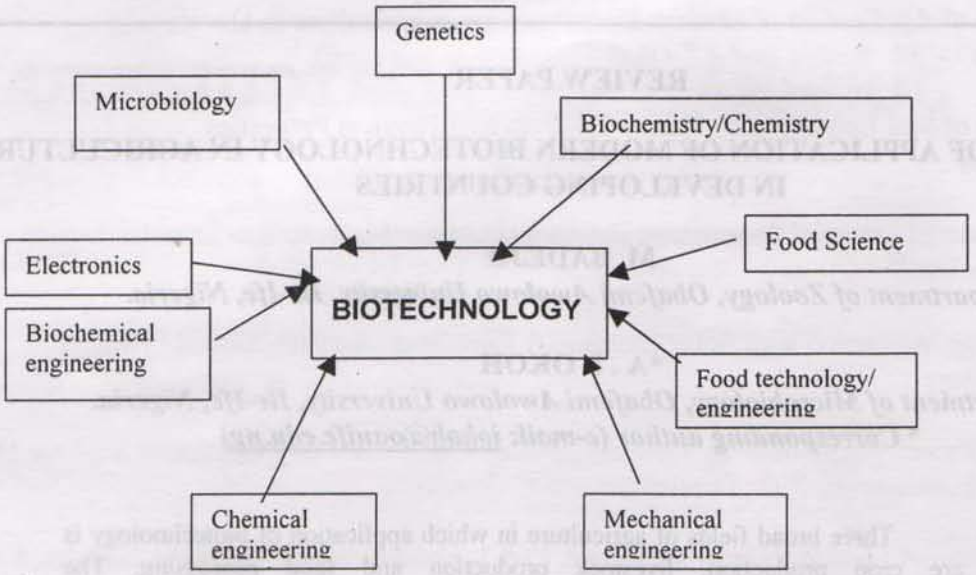


Fig 1. The interdisciplinary nature of biotechnology. (after Lubberding, 1990).

The roots of biotechnology were established around 6,000 BC when the Sumerians and Babylonians in the Near East started beer and wine production. Egyptians were baking leavened bread by 4,000 BC. During this period characteristics of microorganisms were used without any understanding of the processes involved. It was not until the 19th century that Louis Pasteur (1857 - 1976) demonstrated the fermentative ability of microorganisms (Lubberding, 1990). Today, biotechnology has expanded tremendously beyond fermentation processes. Advances in molecular biology, genetic engineering and waste treatment technology have widened the scope of biotechnology. In the agricultural sector, application of biotechnology can be divided into three fields: crop production, livestock production and food processing. In this paper, the biotechnological techniques applied in each of these fields will be described and their application in developing countries will be discussed. A distinction will be made between those techniques that are completely alien to most developing countries and those that have already been in practice for a long time. Modern and indigenous biotechnologies that produce similar products will be compared in order to expose the areas where improvements are needed in indigenous biotechnology.

2.0 CROP PRODUCTION

Various biotechnological techniques by which increased crop productions have been enhanced include tissue culture, microbial inoculation of plants, diagnostic tests, protoplast fusion and plant genetic engineering.

2.1 Tissue culture

This technique is very recent being less than 50 years old. The aim is to regenerate whole plants from single cells in the laboratory and later transfer the plant to the soil. In meristem culture, embryonic cells at the tip of a plant are isolated and cultivated *in vitro*. This simple technique has been used to micropropagate cultivars and to cultivate virus-free plants from virus-infected plants. It has also been used to improve plants that grow slowly and it has been possible to select cells with specific characteristics from any part of the plant, manipulate the media in which they grow and as a result produce plants with characteristics different from the parent plant. Dodds (1989) and Sasson (1989) reported that this technique has been tried on over 50 plant varieties among which are cocoa, grape, lemon, banana, cassava, sweet potato and yam. One problem that is yet to be resolved from tissue culture is the regeneration of whole plants from cells. It is only in rare

cases that this has been achieved (UNDP, 1989). So also, certain unwanted changes usually occur when the genome of a cell is altered and it is extremely difficult to eliminate the traits induced by these changes. The application of tissue culture requires a sterile workplace. It is labour intensive, time consuming and costly. According to Broerse (1990), most plants produced by tissue culture in industrialized countries must be sold for more than $0.25 per plant. Since labour is cheap in many developing countries, production costs are expected to be lower. Unfortunately, this has not been the case in most developing countries, as cost of seeds from tissue cultured plants remained expensive. Unless there is a major breakthrough in tissue culture research that reduces the cost of production tremendously, application of tissue culture in developing countries will bring about an increase in the cost of food.

2.2 Microbial inoculation of plants

This technique is particularly useful in the areas of improved plant nutrition and pest control. Because soils are often low in nitrogen content, good plant growth often means supplementing soil nitrogen with fertiliser nitrogen which are expensive to produce and therefore too costly for many small scale farmers to buy. Fortunately, some plants can form mutually beneficial relationship (symbiosis) with microorganisms which convert atmospheric nitrogen to ammonia, which is then used by the plants to make protein (Roskoski, 1992). Nitrogen fixing bacteria, mycorrhiza fungi and plant growth-promoting rhizobacteria are various biological agents whose artificial inoculation into the soil can increase the nutrient status of soils. Microorganisms that are capable of fixing atmospheric nitrogen include the blue-green algae (Cyanobacteria); soil bacteria such as *Azotobacter* and *Rhizobium* and Actinomycetes. These nitrogen fixers possess the enzyme nitrogenase, which converts atmospheric nitrogen to ammonia. In order to be able to achieve this, *Rhizobium* enters into symbiotic relationship with leguminous plants from where it receives products of photosynthesis and to which it donates ammonia which the plant uses to synthesize proteins (Dixon, 1987; Postgate, 1990). Artificial inoculation of *Rhizobium* into the soil therefore ensures the synthesis of proteins from atmospheric nitrogen by crops. A study carried out in Obafemi Awolowo University has revealed that some *Rhizobium* strains increased the yeild some legumes by between 64 and 251% (Odeyemi et al., 1982).

It has been suggested elsewhere (Okafor, 1994) that if nitrogen fixing bacteria could be engineered into tropical cereals and other crops, their yields would increase without the need for the current heavy expenditure on fertiliser importation. The immense fraud and racketeering involved in fertiliser importation in some African countries is probably an important factor affecting the exploitation of the *Rhizobium* inoculant alternative.

In Nigeria, nitrogen fixation occurs naturally on a large scale in groundnut, which was an important export crop in the 1960s. Cowpea was also widely grown during this period when Africa contributed as high as 90% of the world's cowpea production (Dobereiner and Campello, 1977). The decline in the production of these leguminous foods in Nigeria has reduced the protein intake of Nigerians where many people have been predisposed to fatal diseases as a result of malnutrition and unbalanced diets (Odeyemi and Okoronkwo, 1985).

Some microorganisms are natural pesticides. *Bacillus thuringiensis* for example is an aerobic spore-producing bacterium, which produces a proteinaceous crystal toxic against many insect species (Davison, 1988; Macdonald, 1989). The fungus *Collectrotrichium gloeosporioides* has also been used effectively as a microbial herbicide in rice and Soya bean farming (Broerse, 1990). *Trichoderma* is a commercially produced fungal inoculant which is used to control plant diseases caused by root pathogens (Baker, 1989; Campell, 1989). The use of microbial inoculants in pest control is being encouraged worldwide because of its advantages over the use of chemicals. Some of these advantages include low cost of production, low operator risk and less negative impact on the environment. One disadvantage of microbial inoculants is their sensitivity to environmental changes in the field (Broerse, 1990). For example, commercial *Bacillus thuringiensis* spores are inactivated rapidly by sunlight and variations in moisture and temperature in the field could affect the development, invasive ability, virulence and survival of microbial pathogens in agroecosystems (Carruthers and Haynes, 1986). As a result, special protectants and adjuvants have been formulated to prolong the residual activity of various microbial inoculants in the field (Matanmi, 1995). In order to increase the effectiveness of biocontrol agents in the field, research and development on them is top

on the priority list of international agricultural institutions. It is pertinent to stress here that research and development on microbial inoculants do not cost up to one tenth of the amount spent on chemical pesticides (Broerse, 1990).

Generally, the advantages of microbial inoculant technology, which has not been well developed in many developing countries, are better yields, lower costs and reduced dependence on agrochemicals. Most of them are not difficult to produce. According to Davison, (1988), unsophisticated fermentors of modest volume can be used to produce significant quantities of inoculants whose prospects for improved agriculture in less intensive, low-input agricultural systems are very good. Microbial inoculant has been used to control the pesticide-resistant blackfly vectors of river blindness in West Africa and research in this area is currently being intensified in many developing countries.

2.3 Genetic engineering

In India, the agricultural development policy up till the 1960s was based on strengthening the ecological base of agriculture and the self-reliance of peasant farmers. In 1961, the Ford Foundation launched an intensive Agricultural Development Programme in this country. The aim of this programme was to "release Indian agriculture from the shackles of the past" through the introduction of modern intensive chemical farming (Swaminathan, 1983). This marked the birth of the green revolution in India. Indian farmers and researchers soon discovered that the native varieties of wheat did not respond well to intensive fertilizer applications. This led Norman Bourlaug, the 1970 Nobel laureate to develop, through plant breeding experiments, high yielding varieties (HYVs) of wheat in India. Bourlag's "miracle seeds" were designed to respond well to chemical fertilizer and they were so successful that they were said to have transformed India from "a begging bowl to a breadbasket". The term high-yielding varieties have been criticised because the new seeds do not produce high yields on their own. The only difference between them and the old ones is that they are highly responsive to fertilisers and irrigation water (Shiva, 1991). Unknown to the ordinary Indian farmer, water was responsible for a very high percentage of the increased yield of the new HYVs. This is due to the fact that nitrogen uptake by the plants as a result of artificial fertiliser input upsets their carbon/nitrogen balance, causing metabolic problems which the plants react to by taking up more water. Increased yield therefore did not mean increased nutritive value of wheat produced. Within a few years of introduction of the HYVs, nearly half of the wheat planted in India came from the new seeds. This reduced genetic diversity in Indian agriculture and made agroecosystems highly vulnerable to pests and disease. Although the marketable output of wheat increased significantly, other outputs, which include using the unharvested biomass as fodder for animals and organic fertilisers for soils, were considerably reduced. There was indeed a decrease in ecosystem productivity due to the over-use of resources. In fact, Mander and Goldsmith (1996) had warned that while the world may lack food and suffer from pesticide pollution, the focus of multinational corporations is profit, not philanthropy, which according to Okoh (2001) has been influencing the focus of many research schemes.

The conventional system of plant breeding to produce HYVs has now been replaced by one of the most technical and complex of biotechnological processes. It starts with DNA extraction and the location of a gene from a plant. Using synthesized antisense-RNA, the expression of this gene is blocked so as to detect its purpose when the phenotype of the plant whose gene is blocked is compared with the one whose gene is not blocked. Thus selected genes can be transferred from one organism to another to produce a desired effect. Since 1983, plant biotechnologists have recorded a high degree of success in transferring single genes that control agronomically important traits such as resistance to viruses, insects and herbicides from one plant to the other (Sasson, 1989). Through this technique of gene transfer, it has been possible to reduce the time-span needed to develop a new plant variety from about 10 - 20 years to about 5 - 10 years (Broerse, 1990). This way, genetic engineering will enhance the sustainability of agriculture by solving the very problems affecting conventional farming and will spare the developing world farmers from low productivity, poverty and hunger (Gresshoff, 1996). The problems with the application of this technique in developing countries are enormous. The reagents and enzymes needed are very costly and because of their unstable nature, they cannot be stored for a long time. The laboratory must be well staffed and fully equipped (UNDP, 1989). Such laboratories are mainly located in industrialised countries although their research mandate is specifically directed towards developing countries.

In an overview of the application of biotechnology in developing countries, Broerse (1990) declared that genetic engineering cannot improve agricultural production in developing countries in the short term. It therefore makes sense to focus more on biotechnologies that are not too exotic and can provide short term benefits in developing countries.

3.0 LIVESTOCK PRODUCTION

Many crop residues and agro-industrial wastes contain heavily lignified fibre, which limits digestibility by acting as a barrier to microbial utilisation of cellulose and hemicellulose by microorganisms in the digestive tract of ruminants. This problem can be overcome by degrading the lignin through microbial conversion in the solid state. This biotechnological procedure is called solid state fermentation (SSF) and it has been defined as fermentation processes in which microbial growth and product formation occur on surfaces of solid substrates (Sasson, 1989).

SSF is a very simple biotechnological process which performs best under low moisture conditions (Mudgett, 1986). However, technical problems associated with reduction of contamination are yet to be overcome. So also is the problem of huge costs which makes it a non-profitable means of production of animal feed in a country like Nigeria where many fodder grow naturally in the savannah region where livestock rearing is widely practised (Igboanugo and Badejo, 1998).

Another breakthrough in biotechnology applied in livestock breeding is the production of rDNA vaccines. The Deletion Mutant Vaccine for example removes the gene coding for virulence factors from the genome of a pathogenic organism using restriction enzymes. The organism then becomes non-virulent but it would still be capable of eliciting an immune response (Broerse, 1990). Other rDNA vaccines are the Subunit Vaccine and the Carrier Vaccine. The cost of developing a single rDNA vaccine is about US$ 5 - 10 million and this takes about 10 years! Very few developing countries can afford to invest so much money in this venture. If they do, the cost of meat will be exorbitantly high.

Another technique that has been perfected in the past two decades is embryo transfer technology (ET) (Persley, 1989). ET makes female animals produce more offspring than would be possible with normal reproduction. For example, a cow, which would normally produce four calves in a lifetime, could be made to produce up to 25. This has been successfully practised by veterinary scientists in Asia and Latin America but the problem of huge costs still makes reliance on ET as the hope for increased livestock production in Africa very unrealistic. The problems associated with genetic engineering in animals are more or less the same as the problems in plants. The first gene transfer was done in the mouse in 1980 and since then researchers have worked successfully on a variety of mammals, birds and fish (Persley, 1989). Other techniques such as hormone treatment, protoplast fusion and various diagnostic tests involve sophisticated genetic manipulations. It is unlikely that application of these techniques is feasible for large-scale application in developing countries not only now but also in the future.

4.0 FERMENTATION TECHNOLOGY

The general definition of fermentation implies that it is the process of food spoilage by microorganisms. A more informed definition suggests that fermentation is an industrial process for the production of compounds, mostly by microorganisms in a bioreactor. In all parts of the world, plant and animal materials are fermented traditionally by various bacteria, yeast and fungi to produce foods and alcoholic beverages. In industrialised countries, these traditional fermented products have been refined and the processes have been studied to the extent that the species of microorganisms that are responsible for the fermentation process have been identified. Most of these products are now made in large factories while some are still retained in small factories in the home. Developing countries also have their own share of these products but the processes are poorly studied and the products cannot withstand competition with the imported fermented foods in the market. A list of the different sources of fermented foods in different parts of the world as well as the microorganisms responsible for the fermentation processes is presented in Table 1. In the succeeding sections, the biotechnological processes involved in the production of selected fermented products will be described so as to highlight the similarities and differences in the production processes of similar products in different parts of the world and suggest ways by which the production of the products from developing countries can be made more popular.

4.1 Cottage Cheese and Warankasi

Modern production of cottage cheese from milk involves the use of a 5% starter culture which is usually a blend of *Streptococcus lactis, S. cremoni* and *Leuconostoc citrovorum* (Ayers et al., 1980). Warankasi (Waara) is also a cheese whose production relies on the autochtonous microbial milieu of the fermentation process as well as crude extract of the plant *Calotropis procera* (Sodom apple) for clotting. This process is not as hygienic as the production of cottage cheese and it does not take place under controlled conditions. As a result, the products are of a diverse composition, have low nutritional quality and cannot stay preserved for a long period.

4.2 Ogi

Ogi is a fermented product from maize and other cereals whose production involves a wide array of microorganisms. According to Akinrele (1970), these microorganisms include bacteria such as *Corynebacterium* sp., *Clostridium* sp., *Enterobacter cloacae, Lactobacillus plantarum, Lactobacillus brevis* and *Acetobacter* as well as fungi such as *Cephalosporium, Rhizopus, Oospora, Cercospora, Fusarium, Aspergillus niger, Penicillium, Saccharomyces cerevisiae, Rhodotorula* and *Candida mycoderma. Ogi* is not as nutritious as other cereal-based products such as quaker oats and custard because there is a significant reduction in the nutrients of the cereal during the production process. Akinrele (1966) has reported substantial loss of lysine, tryptophane, riboflavin, thiamine and niacin during the production process of *ogi* from maize. It is however noteworthy to observe that a lot of improvement has been made in the production of ogi. Recent research has revealed that a mixed culture inoculum of *Lactobacillus plantarum, Streptococcus lactis* and *Saccharomyces rouxii* is very suitable for cultured *ogi* production. Akinrele (1964) showed that ogi produced using mixed culture of Lactobacillus and Aerobacter had better nutrients than the unfermented grain and ogi produced traditionally. This is an example of improvement on indigenous technology through research efforts.

4.3 Alcoholic beverages

All alcoholic beverages are produced through the fermentation of carbohydrate base material to give products of various types depending on the process conditions. Lager beer for example is produced by the fermentation of pasteurised wort by a monoculture of yeast usually *Saccharomyces cerevisiae* and *Saccharamyces carlsbergensis* under highly controlled conditions. The process of production is designed to keep away possible microbial contaminants by employing such principles as steeping in antiseptic solution, pasteurisation of wort before yeast pitching, fermentation at very low temperature and pasteurisation of the final product. These control and purification measures are lacking in the production of our indigenous alcoholic beverages where the fermentation process is carried out by a wide array of microorganisms, many of which are yet to be identified. This is the reason why the qualities of many locally brewed alcoholic beverages in Nigeria and many developing countries are inconsistent and low.

Research on production of alcoholic beverages in Nigeria is focused on finding substitutes for the imported ingredients. For example, Sorghum, a popular crop in Nigeria has been found to be a very good substitute for the imported barley. Details of the production process as well as quality of the products have been reported by Ilori (1989). So also, Okoh et al., (1995) and Babalola and Okoh, (1996) have reported that extracts of the local bitter leaf (*Vernonia amygdalina*) compare satisfactorily with imported hops (*Humulus lupulin*) in flavouring sorghum beer. The benefits of these research findings could be exploited and incorporated into local production in Nigeria if the appropriate government authorities establish the necessary legislation requiring the production units concerned to adjusting their production system in such a way as to accommodate these Nigerian alternatives. An attempt at this suggestion was made in the early eighties when the then military government placed a ban on the importation of some materials for which exists alternatives in Nigeria. This policy could be revived, with some modification to making it feasible.

Table 1. Some products of fermentation in different parts of the world

Source	Product	Microorganism used	Region/Country of origin
	Dairy products		
Milk	Yoghurt	*Lactobacillus bulgaricus* + *Streptococcus thermophilus*	Europe
	Cheese	*Streptococcus lactis* or *S. cremoris*	Europe (Netherlands)
	Swiss cheese	*Propionibacterium* spp., *Penicillium roqueforti*	Europe (Switzerland)
	"Waara" and "Fura"	Autochtonous microflora	Nigeria
		Alcoholic beverages	
Barley + other cereals	Ale; beer	*Saccharomyces cerevisiae*, *S. carlsbergensis*	Belgium, Germany, Canada
Rice	Arak	not known	India, SE Asia
Sorghum	Kaffir beer	"	Malawi
Sweet potato	Awamori	n.i.	Japan
Apple juice	Cider	n.i.	U.K.; France; North America
Palmyra juice	Toddy	n.i.	India; SE Asia
Palm flower-stalk juice	Tuwak	n.i.	Indonesia
Maize/ Sorghum	"Burukutu"; "Pinto"	Autochtonous microflora	Nigeria
		Foods	
Wheat and soybeans	Shoyu	*Aspergillus oryzae*, Yeast & *Lactobacillus*	Japan
Soybeans	Tempeh	*Rhizopus oligosporus*	Indonesia
Soybean curd	Sufu	*Actinomucor elegans*	China
Peanut press cake	Ontjom	*Neurospora sitophila*	East Indies
Fish	Fish sauce	Halophilic bacteria	Thailand
Locust bean seed	"Iru" (Dawadawa)	Autochtonous microflora	Nigeria
Melon	"Ogiri"	Autochtonous microflora	Nigeria
Cassava	"Gari", "Lafun", "Fufu"	Autochtonous microflora	Nigeria
Maize + other cereals	"Ogi", "Kunnun", "Soy-ogi"	*Lactobacillus plantarum*, *Streptococcus lactis* *Saccharomyces rouxii*	Nigeria

n.i. - no information

Another area of research to which attention must be focused in Nigeria is in the purification of local biotechnological processes in production of alcoholic beverages. *Burukutu* and *Pito* can also be as popular as

other modern alcoholic beverages if the microorganisms responsible for their production are identified, isolated and cultured for mass production of the beverages. Modern biotechnology could be applied to modify the properties of organisms involved in food processing (Okafor, 1994).

5.0 CURRENT UNRESOLVED PROBLEMS

5.1 Biotechnology (Bt) crops

The so-called 'Bt' crops which produce their own insecticides closely follow the pesticide paradigm, which is itself rapidly failing due to pest resistance to insecticides. Just as insects develop resistance to insecticides with time, so also do they develop resistance to the insecticide in 'Bt' crops with time (Alstad and Andow, 1995). Bt crops violate the basic and widely accepted principle of "integrated pest management" (IPM), which is that reliance on any single pest management technology tends to trigger shifts in pest species or the evolution of resistance through one or more mechanisms (NRC, 1996).

5.2 Locally fermented and genetically engineered foods

It is observed that many developing countries have various local foods that are a product of fermentation but which unfortunately have low quality and short shelf lives. Current research efforts in the improvement of alcoholic beverages in Nigeria and other developing countries should be intensified especially in respect of purification and identification of the microorganisms responsible for each fermentation process. After all, recent evidence has shown that there are potential risks in eating food derived from genetically engineered crops as opposed to foods that are products of fermentation of naturally occurring crops. An example of such a risk is that the new proteins produced in such foods could act themselves as allergens or toxins, alter the metabolism of the food producing plant or animal, causing it to produce new allergens or toxins, or reduce its nutritional quality or value. It is on record that herbicide resistant soya bean contains less isoflavones, an important phytoestrogen present in the conventional soya bean. Isoflavines are believed to protect women from a number of cancers (Altieri and Rosset, 1999).

It has been reported by Lappe and Bailey, (1998) that many genetically engineered foods are beginning to flood the markets in many developing countries such as Argentina and Brazil that import soybean and corn from USA. Nobody can predict all their health effects on consumers, who are usually unaware that they are eating such food. Because genetically engineered (GE) food remains unlabeled, consumers cannot discriminate between GE and non-GE food, and should serious health problems arise, it would be extremely difficult to trace them to their source. Lack of labelling also helps to shield the corporations that could be potentially responsible from liability.

5.3 Biotechnology, hunger and the environmental question

The notion that biotechnology is the magic bullet solution to all of agriculture's ills is not true. The claim by biotechnology companies that genetically altered seeds are essential scientific breakthroughs needed to feed the world, protect the environment and reduce poverty in developing countries has been challenged (Altieri and Rosset, 1999). The prevalence of hunger in a country has nothing to do with the size of the human population. For every densely populated and hungry nation like Bangladesh or Haiti, there is a sparsely populated and hungry nation like Brazil and Indonesia. The world today produces more food per inhabitant than ever before. Enough food is therefore available for the world's teeming population. The real causes of hunger are poverty, inequality and lack of access to food. Too many people are too poor to buy the food that is available that is not evenly distributed globally. Very many people lack the land and resources to grow food themselves (Lappe, et al., 1998).

Moreover, genetically engineered plants have been planted on many millions of hectares globally without proper biosafety standards (Altieri and Rosset, 1999). Ecological theory predicts that the large-scale landscape homogenization with transgenic crops will exacerbate the ecological problems already associated with monoculture agriculture. Unquestioned expansion of this technology into developing countries may not be wise or desirable. There is strength in the agricultural diversity of many of these countries, and it should not be inhibited or reduced by extensive monoculture, especially when consequences of doing so results in serious social and environmental problems (Altieri et al., 1998).

The ecological risk posed by products of biotechnology has not been receiving adequate attention globally. Funds for research on environmental risk assessment are very limited. For example, the USDA spends only 1% of the funds allocated to biotechnology research on risk assessment, about $1-2 million per year. Given the current level of deployment of genetically engineered plants, such resources are not enough to even achieve adequate results. If more funds are made available for agroecologically based agricultural research, such funds would be directed towards finding lasting solutions to all the biological problems that biotechnology is trying hard to solve. More importantly, publicly controlled regulatory regimes for assessing and monitoring the environmental and social risks of biotechnological products and the general activities of the biotechnology industry should be put in place so as to ensure public interest and safety, as against profit.

More food can be produced by small-scale farmers located throughout the world using agroecological technologies (Uphoff and Altieri, 1999). In fact, new rural development approaches and low-input technologies spearheaded by farmers and NGOs around the world are already making a significant contribution to food security at the household, national and regional levels in a few countries in Africa, Asia and Latin America. Yield increases are being achieved by using technological approaches that are based on agroecological principles (van der Werf, 1998a & b), that emphasize diversity, synergy, recycling and integration as well as social processes that emphasize community participation and empowerment (Rosset, 1999). When such features are optimized, yield enhancement and stability of production are achieved, as well as a series of ecological services such conservation of biodiversity, soil and water restoration and conservation, improved natural pest regulation mechanisms as highlighted by (Altieri et al., 1998).

6.0 CONCLUSION

It has been demonstrated in this write-up that application of modern biotechnology in agriculture is of tremendous importance in the areas of crop and livestock production as well as food processing. Specifically, the benefits derived from tissue culture, genetic engineering and solid state fermentation are highlighted and the constraints to their full-scale adoption in developing countries are reported as unresolved technical problems, high cost of operation and inability to ensure sustainability. It is suggested that improvement of plant nutrition and control of pests through microbial inoculation of plants should be encouraged in developing countries due to their high prospects in increasing yield. While many countries in the temperate region are having problems with nitrogen pollution because human activities are speeding up the release of nitrogen from long-term storage in soils and organic matter, tropical soils are highly deficient in this element (Badejo, 2000). Besides, nitrogen is a limiting nutrient in the savannah region of the tropics. Intensive cultivation of fast-growing leguminous trees that would enhance biological nitrogen fixation has been suggested as the only way by which productivity problems in the tropical moist savannah can be solved (Badejo, 1998). It was stressed that biotechnology, as it is been widely applied, has not only failed to solve the problem of hunger, it has also created many environmental problems which can be prevented or solved by employing ecologically sound agroecological technologies.

It is therefore recommended that developing countries (Nigeria inclusive) should as a matter of priority and expediency identify areas of agriculture that could be improved upon using biotechnology, such that the gains of the exercise will be affordable to the citizenry. It should also be the responsibility of governments of developing countries to provide the needed fund and conducive atmosphere required for research and development towards improving existing products. This off course implies that 'round pegs must be put in round holes'. A situation in which people who know nothing about biotechnology are appointed to run biotechnology agencies will certainly be counter-productive and should be avoided. Government should also ensure that the appropriate legislation are put in place to compel the industrial sectors to utilise the products of biotechnology research in developing countries and de-emphasise the continuous importation of materials for which there are alternatives at home.

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INFLUENCE OF SOIL LOOSENING BY ROTARY TILLER ON SOIL PHYSICAL PROPERTIES

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ABSTRACT

Field evaluation were conducted on a clay soil at Shika, Kaduna State, Nigeria, to determine the effects of soil loosening by rotary tiller on soil physical properties. Due to high clay content of the soil, workability is a noteworthy constraint in the area. Rotary tillage significantly (P=0.05) influenced soil bulk density, strength of tilled soil, mean mass diameter of clods, aggregation of particles <2μm, particle size density and porosity. Generally, soil bulk density, soil strength, and particle size density increased with increase in depth from 0-2.5cm depth to 10.0-12.5cm depth beyond of which there was decrease. Aggregation of particles <2μm increased in soil moisture from 11%, w/w at 0-2.5cm depth to 37%, w/w at 12.5-15.0cm depth. The greatest bulk densities of 1.495g cm^{-3} and 1.432g cm^{-3} occurred at 10.0-12.5cm depth on tilled and untilled plots respectively. It is possible to achieve a considerable reduction in the bulk density with one passage of rotary tiller.

KEYWORDS:
soil loosening, rotary tiller; soil physical properties.

1. INTRODUCTION

In recent years, the use of rotary tillers on Fadama (seasinally inundated flood plains and other areas along the banks of streams and courses) farms in the Northern Nigeria is becoming more popular in comparison with other tillage tools among the farmers in the area because it is efficient and it provides clean seedbed. Kawamura (1970), comparing ploughing with rotary tillage, showed a good breakup of the soil by the rotary tillage, more than 45% of clods being less than 10mm in size and reported no differences in yield of rice (Oryza sativa (L.)). Recent rotary tillage studies (Cropping Scheme Report, 1997) indicate that the device inspired enthusiasm and over 75 percent of Fadama farmers in the investigated areas were interested in it.

There are limited data on the effect of soil loosening by rotary tiller on soil physical properties under fadama conditions in this country. Elsewhere, a number of researchers (Mursch, 1961; Broad and Cotton, 1964; Kawamura, 1970; Knizel et al., 1981; Destain and Houmy, 1990; Borresen and Njos, 1993) have reported the performance of rotary tillers though mainly, in upland cropping. Research on machines for seedbed preparation with driven rotary tools has produced variable results, apparently depending largely on soil type, differential soil moisture content, bulk density and soil aggregate stability. Spatial and temporal variation in many soil parameters further complicates data interpretation and comparisons with previous research (Cassel, 1982). Some studies have shown that when soil is compacted, bulk density increases, pore volume decreases, size distribution shifts toward smaller pore size, and pore space continuity decreases (Vomocil, 1957). A compacted soil generally has poor aeration, low nutrient and water availability to crop root and can limit root system development. Tillage may affect soil aggregate stability with subsequent crust formation reducing infiltration and seedling emergence (Unger, 1984). The scarcity of field scale information on the effects of soil loosening on soil physical properties by rotary tiller is a serious limitation to the optimum design and management of the tillage implements. The objectives of this study were to evaluate the influence of soil loosening by rotary tiller on selected soil

physical properties including bulk density, soil strength and aggregation.

2. EXPERIMENTAL METHODS

On-farm trials were conducted in 1999 on fadama farm at Shika, Giwa Local Government Area, Kaduna State. The topography is predominantly very gentle undulating plain. The soil is clay which swells when wet and hardset upon drying, Its morphology is dominated by cracks bounding prisms and fairly developed blocks. The A horizon, usually less than 25cm in thickness is dark, greyish-brown in colour.The rotary tiller with provision for depth adjustment, was coupled to a 7-hp two-wheeled walking tractor. The power from the tractor is transmitted to the rotary tiller via belt and pulley arrangements. Experimental area (0.2ha) was divided into three blocks each consisting of six plots, for a randomized complete block (RCB) deisgn with six treatments (depths) using rotary tiller in three replications. Each plot size was 10m wide x 11m long. The average slope of the field was 0.06%. Thirty soil cores were obtained randomly from the plots using a core sampler at 0-2.5, 2.5-5.0, 5.0-7.5, 7.5-10.0, 10.0-12.5 and 12.5-15.0cm depths for soil analysis. Shrinkage limit was obtained as (Greenland, 1981):

$$S = M - \frac{V - V^o}{W^o} 100 \qquad 1$$

Where;

S = shrinkage limit,
M = moisture content of wet soil, as percentage of the weight of over-dried soil,
V = volume of wet soil,
V^o = volume of dry soil, and
W^o = weight of oven dried soil.

Also, shrinkage ratio (R) was obtained as:

$$R = \frac{W^o}{V^o} \qquad 2$$

W^o and V^o are as defined above.

Soil moisture content was determined gravimetrically and bulk density was obtained using core method as described by Blake and Hartge (1986). Soil resistance to cone penetrometer pressure was measured using a hand-held soil penetrometer (Anderson et al., 1980) with a 30° conical probe, 1.9cm in diameter and mounted on a 0.95cm diameter shaft. Aggregation of soil was evaluated using hydrometer technique in the laboratory as described by Bougoucos (1927). The clod size distance was expressed in terms of mean mass diameter (MMD) calculated in accordance with the procedure explained in the Test Code and procedure for Rotary Tiller (Part 2) (RNAM, 1983) as:

$$MMD = \frac{1}{W\left(D_1A + D_2B + D_3C + ... + D_nN\right)} \qquad 3$$

Where,

MMD is mean mass diameter of soil clods; D_1, D_2, D_3, ... D_n is representative diameter of soil clods retained on a particular sieve, A, B, C, ... N is mass of soil retained on a particular sieve; W is total mass of soil sample. Samples were drawn from a sufficiently large area of the test plots to give a representative

value of MMD. Data were subjected to analysis of variance, with means from significant effects separated by Least Significant Difference (LSD).

3. RESULTS AND DISCUSSION

The soil moisture contents decreased with increase in soil depth (Table 1). Generally, the soil fairly, uniformly moist between 0-5.0 and 10.0 - 12.5cm depth with percent coefficient of variation ranging between 3.327 and 4.992. The uniformity in soil moisture minimized the effects of soil moisture on soil resistance to penetrometer pressure. As from 12.5cm to 15.0cm depth, there was a wide range of soil moisture content with the percent coefficient of variation of 10.531. The soil physical properties and consistency limits of the study area are shown in Table 2. Soil clay contents increased with increase in soil depth. Due to high clay content of the soil, workability is a noteworthy constraint in the investigated area. When wet, the soil is plastic but hard upon drying and the soil tillage becomes very difficult. This partly explains why the tillage device (rotary tiller) is receiving acceptance by farmers in the investigated area by farmers as substitute to human power usage.

Aggregation of particules <2μm increased from 11%, w/w at 12.5cm to 15.0cm depth (Table 3). Similarly, mean mass diameter of clods increased from 14mm at 0cm to 2.5cm depth to 31mm at 12.5cm to 15cm depth. The bonding of fine clay particles form stable aggregates and their breakdown by rotary tillage into silt-sized, led to dense grading size distribution and compaction. Several properties of soil mass changes as it is compressed. Soil resistance to penetrometer pressure increased with increased in soil depth on tilled soil (Table 4). This is partly because of the wet-dry cycles creating more desiccation cracks nearer the surface for rapid water flow which moistened the topsoil more adequately than at greater depths. Generally, there was a sharp increase in soil strength from 1.39MPa at 2.5cm to5.0cm depth to 1.64MPa at 5.0cm to 7.5cm depth. This was followed by gradual increase of soil strength from 5.0cm to 12.5cm depth. Below 10.0cm and 12.5 depth, the rotary tillage effect on soil strength reversed, indicating weak trend towards soil strength as the depth increased. Rotary tillage significantly (P=0.05) affected the soil strength despite the insignificant increase in soil moisture contents with similar soil water contents, produced significantly different soil strength measurements.

Soil bulk density increased with increase in depth on tilled and untilled soil. Similar results were reported by Ehlers et al. (1983) and Roth et al. (1988). The rotary tillage significantly (P=0.05) affected the soil bulk density. There was a gradual increase in soil bulk density on tilled and untilled plots from 0.0 to12.5cm depth beyond of which there was decrease. The greatest bulk densities of $1.495gcm^{-3}$ and $1.432gcm^{-3}$ occurred at 10.0cm to 12.5cm depth on tilled and untilled plots respectively. Soil bulk density and soil strength tended to follow similar patterns with depth. Table 4 shows that the soil bulk density reduced after one rotary tillage operation. It implies that it is possible to achieve a considerable reduction in the bulk density of the seedbed preparation with one passage of rotary tiller. Rotary tillage significantly (P = 0.05) affected the particle size density. Increase in soil depth resulted to decrease in soil porosity. Porosity decreased from $60.3m^3$ per $100m^{-3}$ at 0 - 2.5cm depth to $55.1m^3$ per $100m^{-3}$ at 12.5 - 15.0cm depth. Rotary tillage significantly (P=0.05) affected the porosity of clay.

5. CONCLUSIONS

1. The variable, and frequently adverse, reported effects of seedbed preparation on fadama farms can be reduced or offset by rotary tillage.
2. One operation of rotary tillage was adequate to achieve the desired quality of seedbed with reduction in soil bulk density.
3. Rotary tillage significantly (P =0.05) influenced soil bulk density, strength of tilled soil, mean mass diameter of clods, aggregation of particles <2μm, particle size density and porosity.
4. The soil bulk density, soil strength and particle size density, generally increased with increase in soil depth from 0.0cm to 12.5cm depth.

5. The soil strength, soil bulk density and mean mass diameter of clods look promising as indices for predicting rotary tiller performance and for evaluating the seedbed on the basis of its suitability for crop production.

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Table 1: Mean percent soil moisture content values used in the analysis (gravimetric method; measurements taken on 16th Dec., 1999).

Plot No.	Percent soil moisture content					
	0-2.5cm depth	2.5-5.0cm depth	5.0-7.5cm depth	7.5-10.0cm depth	10.0-12.5cm depth	12.5-15.0cm depth
1	19.7	16.8	16.0	14.0	14.2	12.7
2	20.2	18.1	15.7	15.2	13.4	14.2
3	21.3	18.7	15.0	15.0	14.0	15.0
4	21.0	19.2	16.2	14.6	14.1	11.2
5	20.4	19.6	16.3	14.7	13.8	12.2
6	20.0	18.0	16.0	13.9	13.6	12.1
7	22.3	17.2	17.1	13.8	14.0	13.7
8	20.8	17.7	17.2	14.6	13.2	10.9
9	20.9	17.5	16.6	15.2	13.0	11.1
10	20.7	16.8	15.9	15.3	13.7	11.0
11	22.4	18.3	17.0	15.7	12.9	12.6
12	21.3	19.0	16.2	14.8	12.8	13.4
13	19.4	19.2	16.4	13.2	13.0	13.3
14	20.7	19.7	14.9	13.1	14.2	14.4
15	19.5	19.1	15.8	15.3	14.0	14.8
16	19.3	18.4	16.0	14.8	13.8	14.7
17	20.1	19.2	15.7	15.0	13.5	13.8
18	21.6	19.0	16.5	15.4	13.9	12.9
$\bar{x}$	20.644	18.417	16.139	14.644	13.617	13.000
S.D	0.893	0.896	0.609	0.731	0.453	1.369
C.V(%)	4.326	4.865	3.774	4.992	3.327	10.531

Note : $\bar{x}$ = mean, S.D. = standard deviation; C.V = coefficient of variation.

Table 2: Study area soil particle size distribution and consistency limits

Particle size distribution	Soil depth (cm)	Range	Mean
Clay, %(w/w)	0-5	59-63	61
	5-10	61-65	63
	10-15	61-66	64
Silt, %(w/w)	0-5	26-28	27
	5-10	24-26	26
	10-15	23-27	25
Sand, %(w/w)	0-5	10-14	12
	5-10	9-15	11
	10-15	10-14	11
Consistency limits:	0-5	24.3-26.1	25.9
Shrinkage limit, %	5-10	22.0-23.8	23.5
	10-15	21.7-22.1	22.0
Shrinkage ratio	0-5	1.6-2.1	1.9
	5-10	1.7-1.9	1.8
	10-15	1.8-2.0	1.9
Plasticity index[a], %	0-5	24.3-26.1	25.7
	5-10	25.0-27.9	26.4
	10-15	26.3-29.1	28.8
Slakability, %	0-5	18.2-19.7	19.5
	5-10	17.0-18.4	18.1
	10-15	14.4-16.0	15.4
Workability index, %	0-5	0.84-0.86	0.85
	5-10	0.77-0.82	0.80
	10-15	0.70-0.75	0.72

[a]British standard 1377 (1975).

Table 3: Mean mass diameter of clods and aggregation of the experimental area at six depths as influenced by rotary tillage

Depth (cm)	Mean mass diameter of clods (mm)	Aggregation of particles <2μm (%, w/w)
0-2.5	14a*	11a
2.5-5.0	17ab	16ab
5.0-7.5	18ab	21ab
7.5-10.0	21b	25b
10.0-12.5	22b	32c
12.5-15.0	31c	37d
LSD(P=5%)	6.11	8.74

*means in a column for each variable followed by different letters are significantly different at the 0.05 probability level according to the LSD test.

Table 4: Soil bulk density, particle size density, porosity and soil strength of the experimental area at six depths as influenced by rotary tillage.

Depth (cm)	Soil density (gcm^{-3})		Particle size density (gcm^{-3})	Porosity m^3 per 100^{-3}	Soil penetration resistance (MPa)	
	Before tillage	After tillage			Untilled soil	Tilled soil
0-2.5	1.001a*	0.927a	2.340a	60.3c	1.51a	1.32a
2.5-5.0	1.121ab	1.061a	2.387ab	60.1c	1.62b	1.38a
5.0-7.5	1.207b	1.110b	2.461b	58.4b	1.66b	1.64ab
7.5-10.0	1.325bc	1.438cd	2.488bc	56.2ab	1.84bc	1.71ab
10.0-12.5	1.432c	1.495d	2.521d	50.7a	2.27c	2.01b
12.5-15.0	1.340bc	1.400c	2.500c	55.1ab	2.20c	2.00b
LSD(P=0.05)	0.058	0.047	0.087	9.82	0.97	0.89

*Means in a column for each variable followed by different letters are significantly different at the 0.05 probability level according to the LSD test.

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COMPARISON OF POTENTIAL EVAPOTRANSPIRATION CALCULATION METHODS IN A TROPICAL REGION

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ABSTRACT

Ten methods of estimating potential evapotranspiration (ET_p) were compared with pan ET_p method using monthly climatological data collected from twenty-three agro-meteorological stations, distributed over four climatic regions of Nigeria. In general, the temperature and humidity methods approximated pan ET_p very well in the regions. An adjusted 'modified Blaney-Criddle equation' - approximated best in the sub-equatorial south, tropical hinterland and in the tropical continental north, while, the Blaney-Criddle equation (FAO version) performed best in the high plateaux. The analysis also showed that equations derived from non-tropical climatic conditions, when locally adjusted, could predict ET_p very well in the tropics.

KEY WORDS

Potential evapotranspiration, Prediction method comparison, Climatological data, Tropical region

1. INTRODUCTION

Potential evapotranspiration (ET_p) is an index of climatic demand which can be used to estimate crop evapotranspiration (ET). Knowledge of ET_p is necessary in the development, management and utilization of water resources with particular reference to seasonal and peak water requirements for irrigation. Three basic approaches are used to estimate ET; these are: mass transfer, energy balance and empirical methods. The mass transfer principle requires measurements of wind velocity and humidity at two or more elevations, this makes the method impractical. The energy balance and empirical methods are the most commonly used. The Penman (1963) method is based on the combination of energy balance and vapour transport principles, and has often been used to calculate ET_p under varying conditions (Jensen, 1973; Dooren-bos and Pruitt, 1977). Although the Penman method has a sound theoretical basis, its use is limited by the complex mathematical computations involved and some of the required climatic data are often not available.

In Nigeria and other developing countries, the ability to compute ET rapidly and accurately becomes necessary more especially from meteorological parameters that can be easily measured. In essence, a model that is easy to apply and requires a minimum of the commonly available meteorological parameters is to be prefer-red to a more complex and sophisticated model with comparable accuracy of prediction. This preference has resulted in the formulations of such simple equations as those by Duru (1984), Fapohunda and Ude (1992). The performance of these models and others in common use need to be ascertained in relation to pan evaporation ET_p which is generally considered a good index of potential ET. According to Doorenbos and Pruitt (1977), the pan evaporation phenomenon accommodates the combined effects of radiation, wind, temperature and humidity.

The objectives of this study are, therefore, to compare a number of ET_p calculation methods with ET_p derived from pan evaporation data, and to determine which methods best approximate pan evaporation method under the varying humid to arid tropical climate of Nigeria.

2. PROCEDURE

Ten ET_p calculation methods were compared with the pan ET_p method at twenty-three locations in four climatic regions of Nigeria. The forms of the equations are as follows:

2.1 Thornthwaite method (THNT)

Thornthwaite (1948) proposed a potential ET estimate as:

$$ET_p = 1.6L_d \bullet (10T/I)^A \qquad (1)$$

where ET_p is a monthly estimate of ET,cm; L_d is the daytime hours in units of 12, T is the mean monthly temperature, °C; I is the heat index obtained by summing 12 monthly indices, $i = (T/5)^{1.514}$; and $A = 0.000000675I^3 - 0.0000771I^2 + 0.01792I + 0.49239$.

2.2 Modified Blaney-Criddle model (USDA-SCS version) (BCUS)

The Blaney-Criddle equation as modified by the U. S. Dept. of Agric., Soil Conserv. Serv. (1970) is as follows:

$$ET = K_{SCS} \bullet K_t \bullet P(0.46T + 8.13) \quad (2)$$

where ET is the evapotranspiration for specified crop, mm/day; K_{SCS} is the crop coefficient, K_t is a temperature factor ($K_t = 0.0311T + 2.40$), P is the mean daily percentage of annual day-time hours for the time period, and T is the mean daily temperature during the time period, °C.

2.3 Adjusted 'Modified Blaney-Criddle' method (BCFU)

Fapohunda and Ude (1992) adjusted Eq. 2 by incorporating a relative humidity, R_H term as shown in Equation 3.

$$ET = (a_1 - b_1 \bullet R_H) K_{SCS} \bullet K_t \bullet P(0.46T + 8.13) \quad (3)$$

where a_1 and b_1 are intercept and slope of a linear relationship of ET to R_H, respectively. Other terms are as defined in Equation 2.

2.4 Blaney-Criddle model (FAO version) (BCDP)

Doorenbos and Pruitt (1977) presented a modified version of Equation 2 as follows:

$$ET_p = a_2 + b_2 \bullet P(0.46T + 8.13) \quad (4)$$

where a_2, b_2 are the factors that depend on long-term average minimum relative humidity, daytime wind speed and the ratio of actual to possible sunshine hours; P and T are as defined in Eq. 2.

2.5 Blaney-Morin-Nigeria method (BMND)

Duru (1984) presented a Blaney-Morin-Nigeria model and defined potential ET (mm/day) as:

$$ET_p = r_f(0.45T + 8)(520 - R^{1.31})/100 \quad (5)$$

in which r_f is the radiation ratio, T is the mean daily temperature over a month, °C and R is the mean relative humidity over a month, percent.

2.6 Ivanov method (IVAN)

Ivanov (1954) presented an ET model as follows:

$$ET_p = 0.0018(25 + T)^2(100 - R_H) \quad (6)$$

where ET_p is the potential ET, mm/month; T is the mean air temperature, °C and R_H is the relative humidity, percent.

2.7 Hargreaves method (HRGV)

Hargreaves (1977) defined a potential ET of the form:

$$ET_p = 0.075 \bullet T \bullet Rs/L \quad (7)$$

where ET_p is the potential ET, mm/day; T is the mean daily temperature, °F; Rs is daily solar radiation,

cal/cm²/day and L is the latent heat of water (L = 595.9-0.305(T-32)).

2.8 Jensen-Haise method (JNHS)

Jensen and Haise (1963) defined a potential ET, mm/day, as follows:

$$ET_p = C_T(T - T_x)Rs \quad (8)$$

where C_T is the air temperature coefficient for the location being considered, T is the mean daily air temperature, °C; T_x is a constant for the location and Rs is the total solar radiation for the period, mm.

2.9 Christiansen model (CHRS)

Christiansen and Hargreaves (1969) related potential ET (mm/day) to incoming radiation and climatic factors as:

$$ET_p = 0.492 \bullet Rs \bullet C_{TT} \bullet C_{WT} \bullet C_{HT} \quad (9)$$

where Rs is the incoming solar radiation, mm; C_{TT}, C_{WT} and C_{HT} are temperature, wind speed and relative humidity coefficients, respectively.

2.10 Penman method (PNMN)

The modified Penman combination equation, as presented by Wright (1982), is of the form:

$$ET_p = [(/ +)(R_n+G) + /(+)15.36W_f(e_s-e_d)]L^{-1} \quad (10)$$

where ET_p is the reference crop ET (mm/day), is the slope of the saturation vapour pressure temperature curve (mb/°C), is the psychrometric constant (mb/°C), R_n is the net radiation, (cal/cm²/day), G is the soil heat flux (cal/cm²/day), 15.36 is a constant resulting from unit conversion, W_f is a wind function dependent upon daily wind travel, $(e_s - e_d)$ is the mean daily saturation vapour pressure deficit (mb) and L is the latent heat of evaporation (cal/g).

2.11 Pan evaporation method (EPAN)

Jensen (1973) related potential ET to pan evaporation, E_p by the following:

$$ET_p = C_{ET} \bullet E_p \quad (11)$$

where C_{ET} is a pan coefficient that accounts for differences in pan type and conditions upwind of the pan, and for dissimilarities between plants and evaporation pans.

For ease of data presentation, the ten equations were grouped into these two broad categories: (i) the temperature and humidity equations (THNT, BCDP, BCUS, BCFU, BMND, and IVAN), and (ii) the radiation (JNHS, HRGV, CHRS) and Penman (PNMN) methods, while the pan evaporation method (EPAN) was used as the standard of comparison. Subsequent analyses were based on the four climatic zones into which Nigeria is divided (Iloeje, 1981). The following are short descriptions of the regions and the stations from where climatological data were collected:

- **the sub-equatorial south** extends from the coast to roughly 130 to 160 km inland. The double maximum total annual rainfall increases from 1500 mm in the west to more than 3000 mm in the delta area. Relative humidity is normally over 90% in the early morning, but falls to between 60% and 80% in the afternoon. The stations used in the analysis are Akure, Benin, Calabar, Ibadan, Ikeja, Owerri, Port Harcourt and Warri.

- **the tropical hinterland** comprises a strip of country approxi-mately240 km wide in the middle of Nigeria. The total rainfall is between 1000 and 1500 mm and the region has up to four months of dry season. Relative humidity is over 80% in the morning and falls between 50% and 70% in the afternoon. The stations in this region include Bida, Enugu, Ilorin, Lokoja, Makurdi, Minna and Ogoja.

- **the tropical continental north** consists of the remainder of northern Nigeria, where the annual rainfall is between 500 and 1000 mm. The relative humidity is always low; between 20% and 40% in January, rising to between 60% and 80% in July. The stations in this region are Bauchi, Kano, Kaduna, Maiduguri, Sokoto and Yelwa.

- **the high plateaux** of Jos, Adamawa and Obudu belong to a class by themselves. The temperatures are lower and more equable than in the areas around. The mean monthly temperature for Jos (9° 52'N) ranges from 20°C in August to 25°C in April, and the annual rainfall is 1400 mm; while Yola (9° 13'N) has an annual total of only 1000mm. This region is represented by Jos in the analysis.

Ten years of mean monthly historical weather data were obtained from the Department of Meteorological Services, Oshodi, Lagos on each station. The climatological data collected included temperature (maximum, minimum, wet and dry bulb, and dewpoint), relative humidity, sunshine hours, wind speed and pan evaporation. Since mean solar radiation data could not be obtained from the stations, it was estimated from mean solar radiation for cloud-less skies using an envelope curve suggested by Jensen (1973).

A computer program was written to calculate the ET_p by the eleven methods including EPAN. Long-term averages were calculated for the period of weather data on station by station and on regional basis. The models were statistically compared using the student's t-test (t_{calc}), percentage difference (DIFF), and root mean square (RMS) to evaluate the 'goodness of fit' between ET_p estimates by pan evaporation and other predicting methods.

The student's t-test was calculated using the following equation:

$$t_{calc} = [X_O - X_P]/[(S_O^2 + S_P^2)/n]^{1/2} \quad (12)$$

in which X_O, S_O^2 and X_P, S_P^2 are the means and variances of ET_p (other methods) and pan ET_p, respectively; n is the number of observations. The differences existing between pan ET_p and ET_p by other methods were tested for significance at 5% and 1% levels by comparing t_{calc} with t distributions obtained from statistical tables (Little and Hills, 1978). The percentage difference was estimated from:

$$DIFF = 100(ET_O - EPAN)/EPAN \quad (13)$$

where ET_O, EPAN are ET_p by other methods and pan evaporation, respectively. For the comparison and ranking of ET_p data by the student's t-test and percentage difference, the method that has the absolute value of its t_{calc} or DIFF closest to zero is considered to be the best. The RMS was estimated from the following equation:

$$RMS = (\Sigma D_i^2/N)^{0.5} \quad (14)$$

where D_i is the difference between the EPAN and ET_p (other methods) and N is the number of observations. For the comparison and ranking of ET_p data using RMS, the method that has an RMS closest to zero is the best. The methods were ranked using each of the three statistical parameters individually and an overall rank was given by weighing each parameter equally. In addition, the coefficients for a line ($y = a_3 + b_3 \bullet x$) relating ET_p by a method other than EPAN (y) to EPAN (x), were calculated.

3. RESULTS AND DISCUSSION

3.1 Sub-Equatorial South

Monthly distributions of ET_p as calculated by the temperature and humidity based equations are compared with EPAN in Fig. 1A for the sub-equatorial south. Fig. 1B shows EPAN comparison with ET_p as calculated by the radiation and PNMN methods for the same climatic region. From Fig. 1A, all the methods, except BCFU, over-predicted ET_p all the year round; and except BCUS, all the methods followed similar general trend as EPAN with peak ET_p in February/March and lowest ET_p in August/September. The period of low ET_p corresponds to the rainy season when there are generally lower temperatures and higher relative humidities in the region. All radiation and PNMN methods showed the same general trend as EPAN, but they too grossly over-predicted ET_p all the year round (Fig. 1B). Three ET_p peaks were observed in

February, April and November; with the April peak being followed by a general decline until August.

Table 1 shows the results of the statistical analyses carried out to test the accuracy and goodness of fit of the ET_p predicting methods with EPAN. All the methods, except BCFU, are significantly different ($t_{calc} > 2.201$) from EPAN at 5% level. The significant differences are probably due to the failure of these models, developed from non-tropical data, to adequately account for the reduced radiation levels due to cloud cover in this humid region. Despite these differences, most of the tested methods (THNT, BCDP, BCFU, BMND, IVAN, CHRS and PNMN) are highly correlated ($r > 0.75$) with EPAN; only BCUS is negatively correlated ($r = -0.58$). It is noteworthy, however, to observe that when an adjustment factor (with $a_1 = 2.50$, $b_1 = 0.027$ in Eq. 3) for user estimates of relative humidity was introduced into BCUS, a better approximation of EPAN was obtained with BCFU ($r = 0.95$). The aggregate ranking of the statistical parameters (t_{calc}, RMS and DIFF) shows that the BCFU compares most favourably with EPAN.

Table 1. Values of statistical parameters used for comparing ET_p calculation methods in the sub-equatorial south.

ET_p Methods	Statistical Parameters of Evaluation						Aggr.
	Linear Regression Coefficients			t_{calc}	RMS	DIFF	Rank
	a_3	b_3	r		mm/day	(%)	
THNT	2.90	0.87	0.78	7.97**	2.66	116.7	8#
BCDP	1.92	0.65	0.90	4.22**	1.19	51.0	3
BCUS	7.41	-0.84	-0.58	8.66**	3.67	148.1	10
BCFU	-0.12	0.93	0.95	-0.90	0.36	-12.4	1
BMND	1.96	0.74	0.95	4.99**	1.40	61.8	5
IVAN	-0.31	1.70	0.99	2.89*	1.36	56.1	4
HRGV	3.49	0.56	0.67	8.79**	2.56	111.7	8#
JNHS	2.89	0.52	0.69	6.63**	1.90	81.4	6
CHRS	1.25	0.78	0.88	2.58*	0.83	33.6	2
PNMN	2.81	0.79	0.82	7.73**	2.39	105.0	7
EPAN	0.00	1.00	1.00	0.00	0.00	0.0	-

*$|t_{calc}| > t_{0.05,11} = 2.201$, i.e., sig. diff. exist at 5% level

**$|t_{calc}| > t_{0.01,11} = 3.106$, i.e., sig. diff. exist at 1% level

[a]Aggr Rank = Equally weighted rank of t_{calc}, RMS and DIFF

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3.2 Tropical Hinterland

Temperature and humidity based equations are compared with EPAN in Fig. 2A, while, the solar radiation and PNMN methods are shown in Fig. 2B for the tropical hinterland. There are no noticeable differences in the estimates by the different methods relative to the EPAN when checked against their performances in sub-equato-rial south. However, all the methods except IVAN, under-predicted ET_p in the dry season (mid-November to mid-March) and over- predicted it for the rest of the year.

Table 2 shows that all the methods tested are not significantly different from EPAN at 5% level ($t_{calc} < 2.201$). The methods, especially BCDP, BCFU, BMND, IVAN, CHRS and PNMN, are all highly correlated ($r > 0.80$) with EPAN, but BCFU has the closest approximation as shown by the aggregate ranking of t_{calc}, RMS and DIFF.

3.3 Tropical Continental North

Figs. 3A and 3B compare the temperature and humidity based methods, the radiation and PNMN methods, respectively, with EPAN in the tropical continental north. There are two observable ET_p peaks, one in February/March and the other in November. While the temperature and humidity equations have pronounced peaks, they are not so obvious in the radiation and PNMN methods since their ET_p predictions vary less within the year. Apart from IVAN, which over-predicted ET_p all the year round, the other methods under-predicted ET_p in the dry season (October to May) and over-predicted it in the rainy season. This region is characterized by semi-arid to arid conditions with generally higher temperatures than the two preceding regions.

Table 2. Values of statistical parameters used for comparing ET_p calculation methods in the tropical hinterland.

ET_p Methods	Statistical Parameters of Evaluation: Linear Regression Coefficients a_3	b_3	r	t_{calc}	RMS mm/day	DIFF (%)	Aggr. Rank
THNT	3.70	0.39	0.62	1.45	2.05	26.8	5
BCDP	2.91	0.36	0.92	0.31	1.45	5.3	3
BCUS	6.88	-0.27	-0.49	2.03	3.35	36.4	10
BCFU	1.20	0.73	0.93	0.06	0.87	1.1	1
BMND	2.83	0.49	0.98	0.93	1.33	16.3	4
IVAN	1.01	1.23	0.99	1.87	2.09	47.0	9
HRGV	4.74	0.18	0.59	1.85	2.27	30.3	7
JNHS	4.41	0.19	0.60	1.41	2.11	23.2	6
CHRS	2.69	0.37	0.82	0.04	1.50	0.6	2
PNMN	4.03	0.41	0.89	2.11	2.06	36.4	8
EPAN	0.00	1.00	1.00	0.00	0.00	0.0	-

*Aggr Rank = Equally weighted rank of t_{calc}, RMS and DIFF

The statistical analysis of Table 3 shows that only CHRS is significantly different from EPAN at 5% level. Three methods (BCDP, BMND and IVAN) have the best linear correlations with EPAN ($r \geq 0.85$), but BCFU best approximates the shape of EPAN considering the aggregate ranking of t_{calc}, RMS and DIFF.

Table 3. Values of statistical parameters used for comparing ET_p calculation methods in the tropical continental north

ET_p Methods	Statistical Parameters of Evaluation: Linear Regression Coefficients a_3	b_3	r	t_{calc}	RMS mm/day	DIFF (%)	Aggr. Rank
THNT	4.57	0.10	0.15	-1.96	4.27	-30.0	9
BCDP	3.81	0.23	0.85	-2.06	3.24	-27.0	7
BCUS	7.19	-0.19	-0.34	-1.68	4.55	-24.3	8
BCFU	2.22	0.64	0.74	-0.38	2.24	-6.4	1
BMND	3.48	0.36	0.90	-1.32	2.52	-18.0	4
IVAN	1.72	0.98	0.99	1.13	1.60	20.1	3
HRGV	5.76	0.04	0.18	-1.60	3.52	-20.7	6
JNHS	6.15	0.04	0.17	-1.15	3.36	-15.0	5
CHRS	4.02	0.13	0.50	-2.61*	3.87	-34.1	10
PNMN	5.21	0.21	0.72	-0.82	2.74	-10.8	2
EPAN	0.00	1.00	1.00	0.00	0.00	0.0	-

*Aggr Rank = Equally weighted rank of t_{calc}, RMS and DIFF

3.4 High Plateaux

The shapes of the annual distribution of ET_p by the different methods (Figs. 4A and 4B) are similar to those found in the tropical continental north, but, the actual monthly ET_p values are generally lower probably due to the lower temperatures in the high plateaux. The temperature and humidity methods, except BCUS (Fig. 4A), have much closer ET_p values to those of EPAN than the radiation and PMNN methods (Fig. 4B) especially in the wet season (April to October). While the measured EPAN shows only a peak ET_p in the year, most of the empirical methods show a mini-mum of two peaks.

Table 4 shows that none of the ET_p methods is signifi cantly different from EPAN at 5% level. Six of the methods (BCDP, BCFU, BMND, IVAN, CHRS and PNMN) have high linear correlations ($r \geq 0.80$) with EPAN, but, it is BCDP that has the smallest monthly deviations from EPAN and therefore, the closest to pan ET_p statistically.

4. SUMMARY AND CONCLUSIONS

Ten methods of ET_p calculations were compared to the pan evaporation method using ten years of weather record at each of the twenty-three locations grouped under the four climatic regions of Nigeria. The results demonstrated that, in general, the temperature and humidity equations approximated pan evaporation ET_p well and better than the radiation and Penman equations in all the regions. An adjusted 'modified Blaney-Criddle equation' (BCFU) approximated pan evaporation ET_p best in the sub-equatorial south, tropical hinterland and tropical continental north; while, the Blaney-Criddle equation (FAO version) (BCDP) performed best in the high plateaux.

The study clearly showed that ET_p equations developed from non- tropical conditions might be made to predict ET_p satisfactorily if suitably adjusted with local data. The modified Blaney-Criddle equation (BCUS), without local adjustment, poorly approximated pan ET_p and was actually negatively correlated to it in all the four climatic regions of Nigeria. But, when corrected by a user estimate of relative humidity, the resulting BCFU model gave the best approximation to pan ET_p in the regions.

Evaporation data are relatively easy to obtain and can be very reliable if the evaporation site is maintained in a suitable and consistent manner. However, if evaporation data are collected in poorly maintained installations, the estimates are no longer as accurate as those based on good meteorological data, in that case, the BCFU or BCDP can provide ready and handy alternatives to pan evaporation ET_p in the four climatic regions of Nigeria.

Table 4. Values of statistical parameters used for comparing ET_p calculation methods in the high plateaux

ET_p Methods	Statistical Parameters of Evaluation						
	Linear Regression Coefficients			t_{calc}	RMS	DIFF	Aggr. Rank
	a_3	b_3	r		mm/day	(%)	
THNT	3.86	0.12	0.23	-0.65	2.90	-12.1	7#
BCDP	3.34	0.34	0.95	-0.05	1.87	-0.8	1
BCUS	6.35	-0.24	-0.50	0.02	3.64	0.4	4
BCFU	1.39	0.69	0.86	-0.16	1.44	-3.5	3
BMND	2.92	0.45	0.96	0.15	1.57	2.7	2
IVAN	1.25	1.12	0.99	1.48	1.94	36.5	9
HRGV	5.07	0.12	0.61	0.67	2.55	11.1	6
JNHS	5.51	0.13	0.57	1.26	2.70	21.3	10
CHRS	3.44	0.26	0.80	-0.36	2.14	-6.2	5
PNMN	4.63	0.30	0.86	1.21	2.27	21.0	7#
EPAN	0.00	1.00	1.00	0.00	0.00	0.0	-

[a]Aggr Rank = Equally weighted rank of t_{calc}, RMS and DIFF
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NOTATION

List of symbols used

A heat index exponent in TNTH equation
a_1,b_1 intercept and slope of linear regression of relative humidity and ET in Fapohunda and Ude (1992) equation long-term mean minimum relative humidity, daytime
a_2,b_2 wind speed and sunshine ratio factors in BCDP model
a_3,b_3 intercept and slope of a line, $y = a_3 + b_3x$
BCDP ET_p method by Doorenbos and Pruitt (1977)
BCFU ET_p method by Fapohunda and Ude (1992)
BCUS ET_p method by USDA-SCS Techn. Staff (1972)
BMND ET_p method by Blaney-Morin-Nigeria (Duru, 1984)
C_{ET} pan coefficient in EPAN method
CHRS ET_p method by Christiansen and Hargreaves (1969)
C_{HT} relative humidity coefficient in CHRS model
C_T air temperature coefficient in JNHS model
C_{TT} temperature coefficient in CHRS equation
C_{WT} wind speed coefficient in CHRS equation

DIFF percent difference between pan ET_p and other methods
e_d saturation vapour pressure at dewpoint temperature, mb
e_s mean saturation vapour pressure at maximum and minimum daily temperatures, mb
E_p pan evaporation, mm
EPAN ET_p method using pan evaporation data
ET evapotranspiration, mm/day
ET_p estimated potential evapotranspiration, mm/day
G soil heat flux, cal/cm²/day
HRGV ET_p method by Hargreaves (1977)
I heat index in TNTH equation
IVAN ET_p method by Ivanov (1954)
JNHS ET_p method by Jensen and Haise (1963)
K_{SCS} crop coefficient in BCFU and BCUS models
K_t temperature factor in BCFU and BCUS models
L latent heat of evaporation, cal/g
L_d daytime hours in units of 12 in TNTH equation
P mean daily percentage of annual daylight hours
PNMN Penman ET_p method as presented by Wright (1972)
r coefficient of correlation
r_f radiation ratio in BMND equation
R,R_H relative humidity, percent
RMS root mean square, mm/day
R_n net radiation, cal/cm²/day
Rs incident solar radiation, cal/cm²/day
T mean temperature for the period, °C
t_{calc} calculated t-test values
THNT ET_p method by Thornthwaite (1948)
T_x location constant in JNHS model
W_f wind function in PNMN equation
x pan ET_p in regression analysis, mm/day
y predicted ET_p by methods other than EPAN, mm/day
Δ slope of the saturation vapour pressure-temperature curve, mb/°C
γ psychrometric constant, mb/°C

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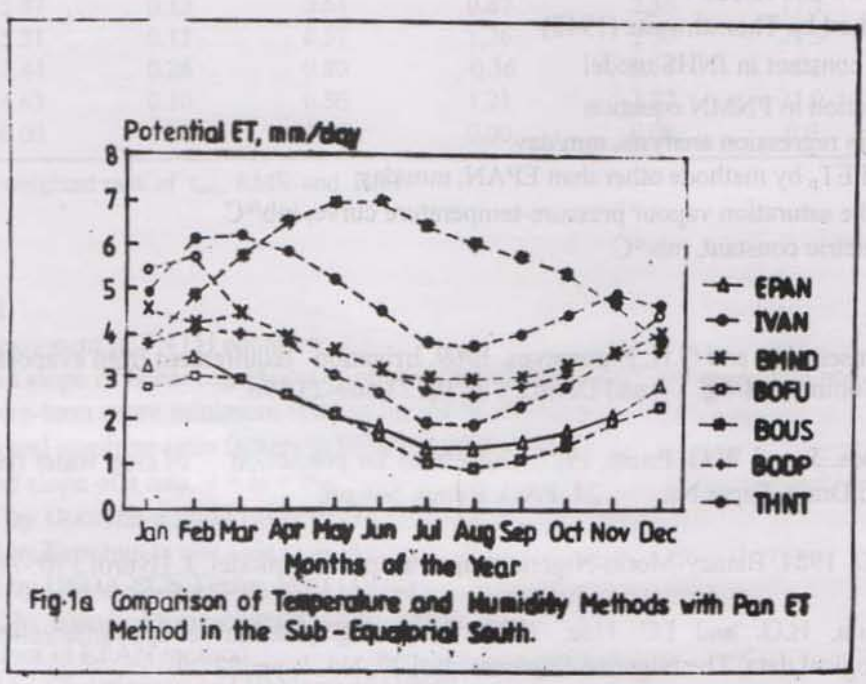


Fig.1a Comparison of Temperature and Humidity Methods with Pan ET Method in the Sub-Equatorial South.

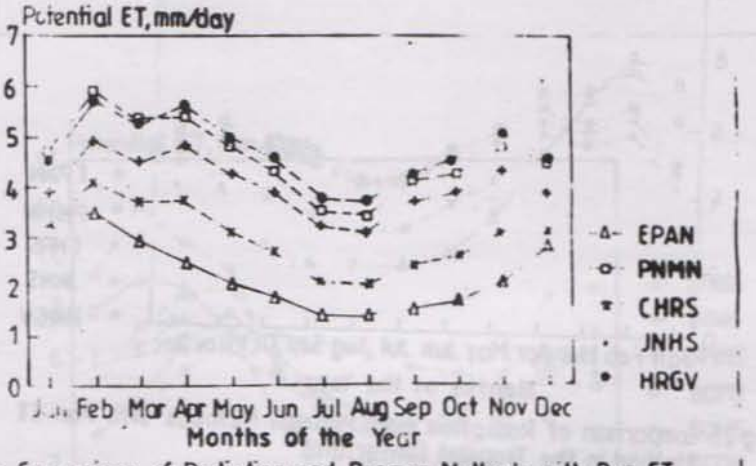


Fig.1b Comparison of Radiation and Penman Methods with Pan ET Method in the Sub-Equatorial South.

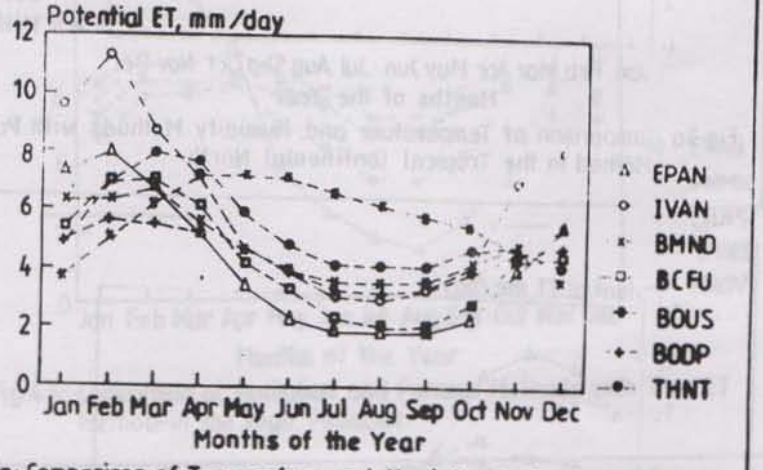


Fig.2a: Comparison of Temperature and Humidity Methods with Pan ET Method in the Tropical Hinterland

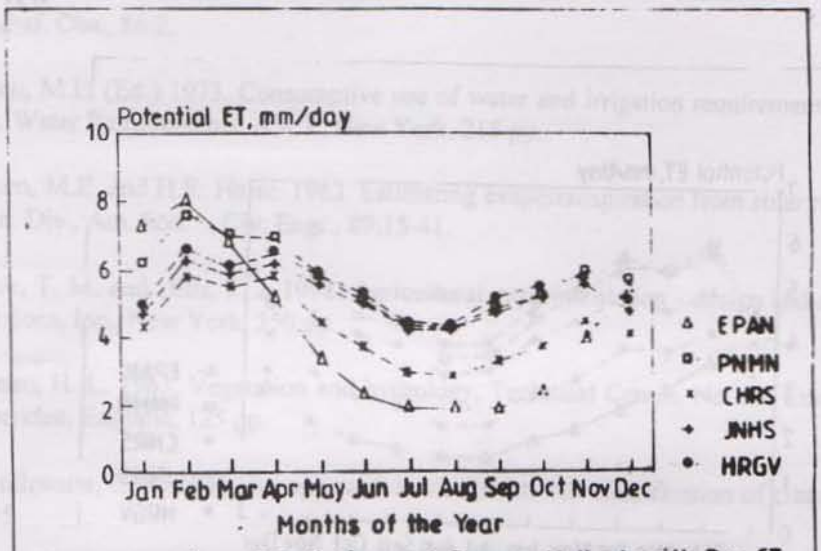


Fig.2b: Comparison of Radiation and Penman Methods with Pan ET Method in the Tropical Hinterland.

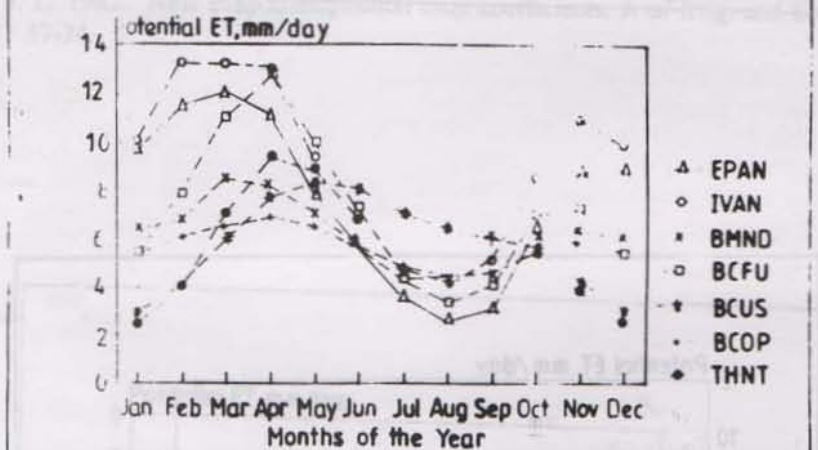


Fig.3a: Comparison of Temperature and Humidity Methods with Pan ET Method in the Tropical Continental North

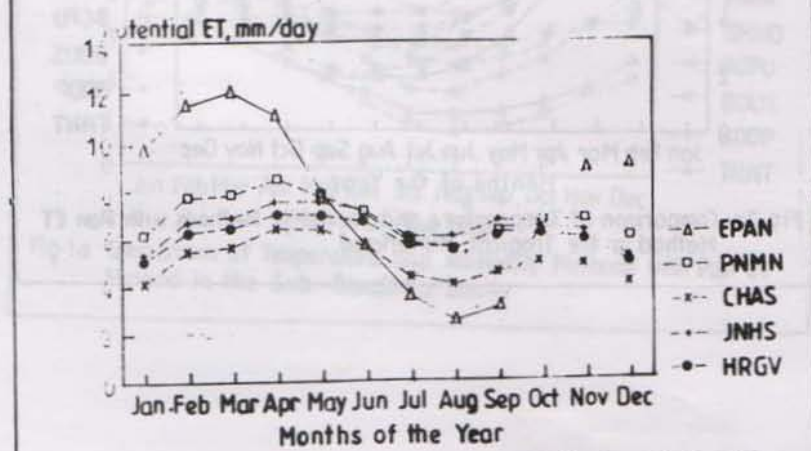
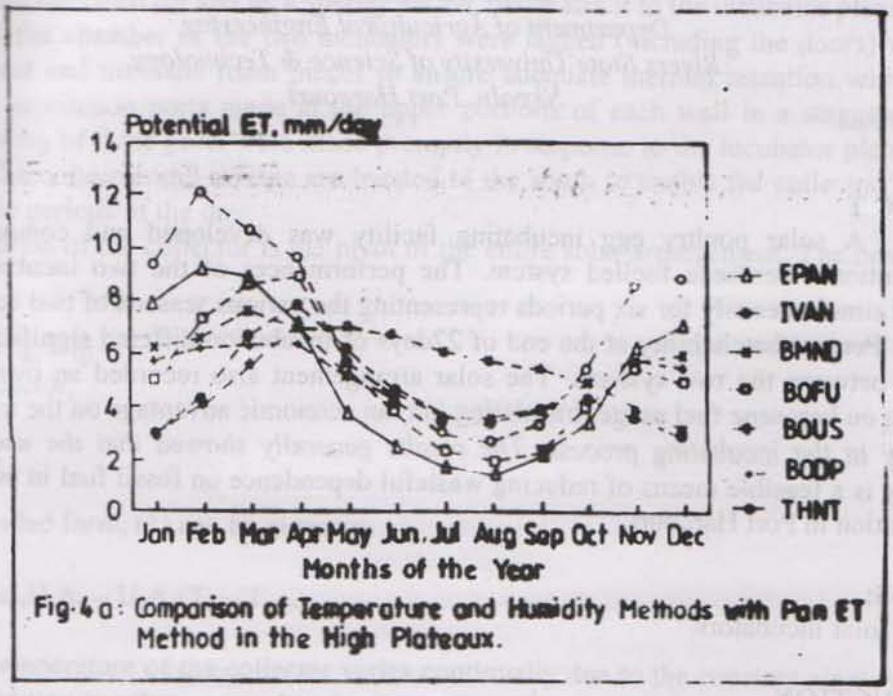
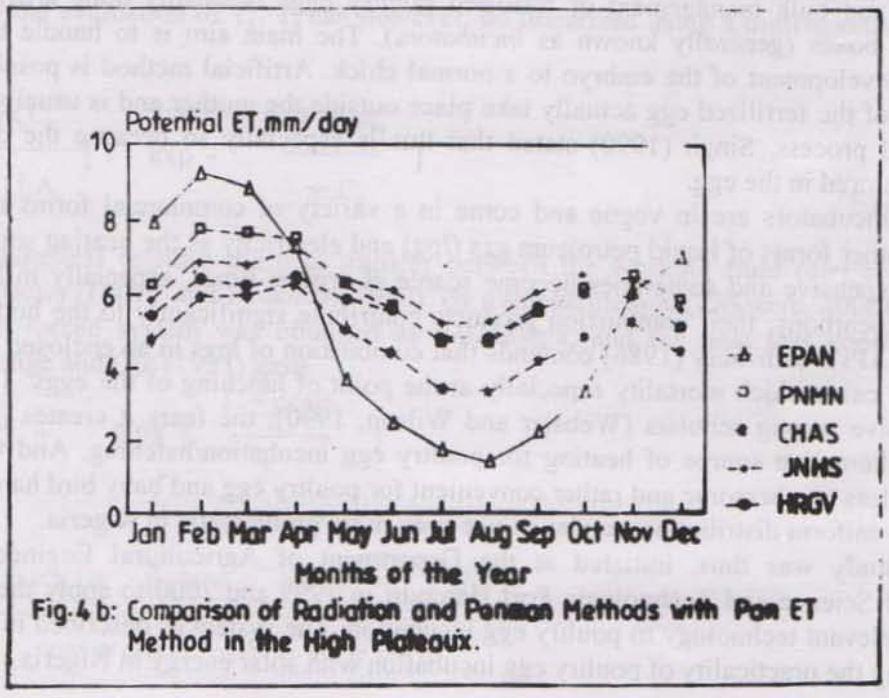


Fig.3b: Comparison of Radiation and Penman Methods with Pan ET Method in the Tropical Continental North



Fig·4 a: Comparison of Temperature and Humidity Methods with Pan ET Method in the High Plateaux.



Fig·4 b: Comparison of Radiation and Penman Methods with Pan ET Method in the High Plateaux.

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POULTRY EGG INCUBATION WITH SOLAR ENERGY – A PILOT STUDY FOR PORT HARCOURT, NIGERIA.

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ABSTRACT

A solar poultry egg incubating facility was developed and compared with conventional kerosene fuelled system. The performances of the two incubators were tested simultaneously for six periods representing the various seasons of two consecutive years. Percent hatchability at the end of 22days of incubation differed significantly ($p = 0.05$) between the two systems. The solar arrangement also recorded an over all 71% saving on kerosene fuel usage, translating into an economic advantage on the use of solar energy in the incubating process. The results generally showed that the use of solar energy is a feasible means of reducing wasteful dependence on fossil fuel in poultry egg incubation in Port Harcourt.

KEY WORDS:
solar energy, solar incubators.

1. INTRODUCTION

Intensive and bulk management of fertilised poultry eggs is usually done artificially in specially prepared egg boxes (generally known as *incubators*). The main aim is to handle the eggs to ensure satisfactory development of the embryo to a normal chick. Artificial method is possible because major development of the fertilized egg actually take place outside the mother and is usually an intensification of the natural process. Singh (1990) stated that this is especially so because the developing embryo utilizes food stored in the egg.

Artificial incubators are in vogue and come in a variety of commercial forms most of which use kerosene or other forms of liquid petroleum gas (lpg) and electricity as the heating source. These sources of heat are expensive and sometimes become scarce at critical times, especially in Nigeria. Moreover, lpgs are hydrocarbons; their combustion products contribute significantly to the body of hazardous air pollutants (HAPs). Sainsbury (1986) contends that combustion of lpgs in an enclosed chamber, results in products that cause chick mortality especially at the point of hatching of the eggs. This though has not been conclusive among scholars (Webster and Wilson, 1990); the fears it creates justify the need for seeking an alternative source of heating for poultry egg incubation/hatching. And whereas the use of electricity is less cumbersome and rather convenient for poultry egg and baby bird handling purposes, the cost and non-uniform distribution, render its use even more problematic in Nigeria.

A pilot study was thus, initiated at the Department of Agricultural Engineering, Rivers State University of Science and Technology, Port Harcourt in 1999 and 2000 to apply the potentials of solar energy and relevant technology to poultry egg incubation. The system as described in this paper is aimed at establishing the practicality of poultry egg incubation with solar energy in Nigeria.

2. THEORY

2.1 System Description

The incubator on solar heating was installed out-doors and housed in a miniature building (Fig. 1). A flat plate collector made active by an ac/dc fan is connected to the rock-bed heat storage box. The collector is inclined 17^{0}C in relation to Port Harcourt's geographical latitude. The heat storage box receives heat from the collector and by a spongy action, dissipates it to the incubator plenum. The internal wall surfaces of the chamber of the two incubators were lagged (including the doors) with a casing of combined sawdust and urethane foam pieces to ensure adequate thermal retention within the chamber with controlled ventilation ports made at the upper portions of each wall in a staggered manner. The opening and closing of these ports were made promptly in response to the incubator plenum temperature and humidity. The collector and storage are located to the south to enable the collector 'see' the sun all through sun shine periods of the day.

The effectiveness of the collector is the pivot of the entire solar arrangement. The heat balance of the collector is

$$q_u = q_a - q_l \qquad 1$$

for flat-plate collector,

$$A_c = A_b \qquad 2$$

Thus in an expanded form, (1) can be given as

$$q_u = \lambda\alpha_s H_s A_c - U_c A_c (T_c - T_{amb}) \qquad 3$$

The surface temperature of the collector varies continually due to the constant air movement over the glass panel in addition to other cover plate factors such as dust, water droplets, bird droppings, etc. these add ambiguity to the evaluation of T_c. T_c can however, be linearized using a dimensionless factor, F_R as (Zibokere, 2000)

$$F_R = \frac{m_c C_p}{U_c A_c}\left[1 - \exp - \frac{F^1 U_c A_c}{m_c C_p}\right] \qquad 4$$

F^1 is also dimensionless relating the heat transfer between the working fluid (air) and the absorber surface of the collector (Duffie and Beckman, 1980). By a smoke method (Zibokere, 2000), the mass flow rate, m_c in a fan forced system was obtained as 0.0248kg/s; and the heat loss coefficient, U_c was 15kJ/m^{2}hr^{0}C. Alonge and Oje (1997) gave

$$H_s = 0.02R_b + 0.98\left[\frac{1 + \cos\beta}{2}\right] \qquad 5$$

where

$$R_b = \frac{\cos\delta\cos(\varphi - \beta)\cos\omega - \sin(\varphi - \beta)\sin\delta}{\cos\varphi\cos\omega\cos\delta + \sin\varphi\sin\delta} \qquad 6$$

and

$$\delta = 23.5\sin\left[360\left(\frac{284 + n}{365}\right)\right] \quad \text{(Duffie and Beckman,1980)} \qquad 7$$

For n values ranging from 1 through 365,

$R_b = 0.98$

bringing average H_s for Port Harcourt solar zone as

$H_s = 271.7 W/m^2$

Applying all necessary parameters in (3) and (4), the average daily thermal transmission efficiency of the flat plate collector in this work was 48% (Table1).

3. MATERIALS AND METHOD

Two, laboratory 2-crate capacity poultry egg incubators were acquired and adapted for the purpose of this study. One was run on the conventional kerosene fuel heating, and the other on solar heating. The one on solar heating was adjusted to accommodate solar heating devices including kerosene fuel supplemented heating. This was necessary because whereas solar energy is intermittent during the day with a night time absence, poultry eggs require continuous presence of a correct measure of heat to incubate properly. The chamber, plenum, and ventilation were all redesigned to conform to requirement for solar energy application. A rock bed heat storage facility was also installed as part of the solar arrangement to balance off any fluctuating heat.

Circulation of heated air through the system on solar arrangement was controlled by a differential temperature controller connected to the ac/dc fan actuated by an ether capsule thermostatic micro-switch set at 39^0C with a resolution of less than 0.5^0C. The relevant incubator humidity range of 54 – 58% (Leslie *et al*, 1997) was obtained using a cloth fabric dipped in a constant-head water pan. The eggs were intermittently turned using the in-built crank device.

3.1 Experimental Procedure

Fertilized eggs for all the live tests were obtained by arrangement, from Igwe Giant Poultry Farms, Rumuewhor, Rivers State. Incubation tests were conducted for five relative seasons of two years (1999/ 2000 and 2000/2001). Each live test was preceded by a proof-of-concept examination to first ascertain the reliability of the thermal capacity of the solar arrangement. This is important because the system requires strict maintenance of the incubating temperature range of 38.3 – 39.4^0C - a range that is critical especially within the first four days of incubation. At the end of each live test (21 – 22 days of incubation), the number of eggs hatched was counted and percent hatchability was recorded.

4. RESULTS AND DISCUSSION

The thermal performance of the solar arrangement is summarized in Table 2. The figures were obtained from the proof-of-concept test runs. Thermal values were considered adequate in relation to the temperature range requirement of incubating eggs. The different curves in Fig.2 show that the heat storage facility was able to retain and sustain the heat in the incubating plenum keeping the temperature at about the range required even far beyond the sun shine periods of the day. With the curves narrowing out at the late night periods, obviates the need for supplementary heating from the kerosene lamps in the solar arrangement.

Thus, the kerosene fuel consumed to provide this supplementary heating is shown in Table 3. On the average, about 71% less kerosene was consumed compared to the consumption in the non-solar arrangement. The savings on kerosene is obviously substantial when translated to economic terms. It also proves to be a feasible measure to decrease dependence on fossil fuels with hydrocarbon content, the combustion products of which are environmentally unfriendly (Kiely, 1998).

The hatchability record in Table 3 shows that the solar arrangement scored about 80% and the conventional system 78%. Though hatchability may not be a function of heat source, the difference is significant ($p = 0.05$). No reason can immediately be adduced for this biological advantage. Similar observations were however, observed by Zibokere (2000) on solar energy chick brooding, Rokeby *et al* (1983) on broiler stocks, Schutte *et al* (1989) on swine nurseries and Jordan (1979) on turkey birds.

5. CONCLUSION

The results in this work have shown that the use of solar energy for poultry egg incubation is a feasible method for decreasing reliance on fossil fuel that are environmentally unfriendly. The data obtained is an indication that the frontiers of solar heating can be practically extended to relevant agricultural applications even in the less sunny period of the year in the Port Harcourt metropolis.

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NOTATION

A_c = collector area, m^2
c_p = specific heat of air, kJ/kg K
F^1 = collector efficiency factor, %
F_R = heat removal factor
H_s = radiation intensity (or insolation) on the collector, W/m^2
m_c = air mass flow rate through the collector, kg/s (use a mean value of 0.0248kg/s)
n = day of the year starting 1st January
q_a = absorbed solar heat energy component, W
q_l = total heat loss component, W
q_u = useful heat energy gained, W/m^2

R_b = tilt factor
T_{amb} =ambient temperature, °C
T_c = collector outlet temperature, °C
U_c = collector heat loss conductance, kJ/ m^2hr K
α_s = solar heat absorptance
β = collector tilt ange, °
δ = declination angle, °
μ_{air} = viscosity of air, kg/m s
ρ_{air} = density of air at mean collector temperature, kg/m^3
η = mean collector daily efficiency, %
λ = effective solar transmittance of the collector glass
ε_b = emittance of the absorber plate

Table 1 Summary of Solar Parameters

Collector

Parameters	Values
Glazing surface area	$2m^2$
Glass thickness	0.003m
Air duct gap	0.035m
Insulating air gap	0.01m
Tilt angle	17^0
No. of glass panels	1
Efficiency factor, F^1	68%
Glass transmittance – absorptance, $\lambda\alpha_s$	88%
Heat loss coefficient, U_c	15kJ/m^2hr^{0}C
Heat flow capacitance, m_c/A_c	0.0084kJ/ m^2s
Mean daily collector efficiency, η	49.8%

Table 2 Mean Maximum Incubator Chamber Temperature
(values obtained from proof-of-concept tests)

Date	Mean collector outlet temperature, ^{0}C	Mean incubator chamber temperature, °C*
Jan, 1999	73	62
Jun. 1999	64	56
Nov. 1999	69	58
Apr. 2000	70	60
Sept. 2000	71	60
Dec. 2000	72	61

* values when 90% of all ports were closed

Table 3 **Performance of the Solar Powered Poultry Egg Incubator**

Date	Hatchability % *		Kerosene consumption litres*		
	solar	cs+	solar	cs	savings,%
Jan, 1999	81	78	7	43	83.7
Jun. 1999	77	76	18	46	60.9
Nov. 1999	*79*	*75*	*14*	*47*	*70.2*
Apr. 2000	82	80	10	44	77.3
Sept. 2000	76	78	20	45	55.6
Dec. 2000	84	81	8	46	82.6

* all values corrected to the nearest whole number.

\+ cs = conventional system.

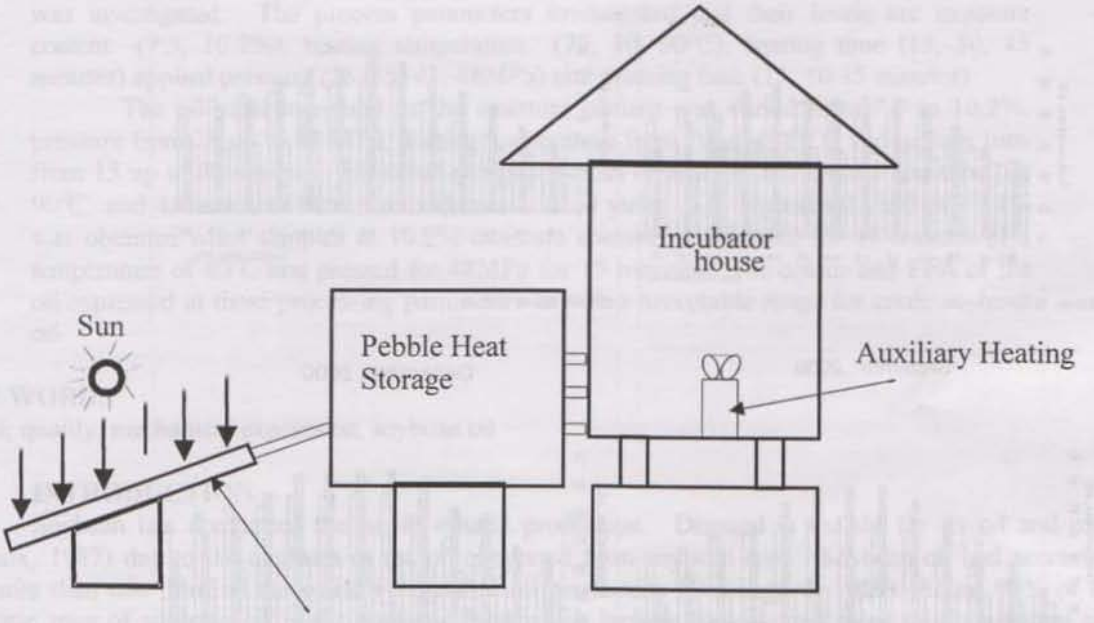


Fig. 1 Schematic arrangement of the solar incubator.

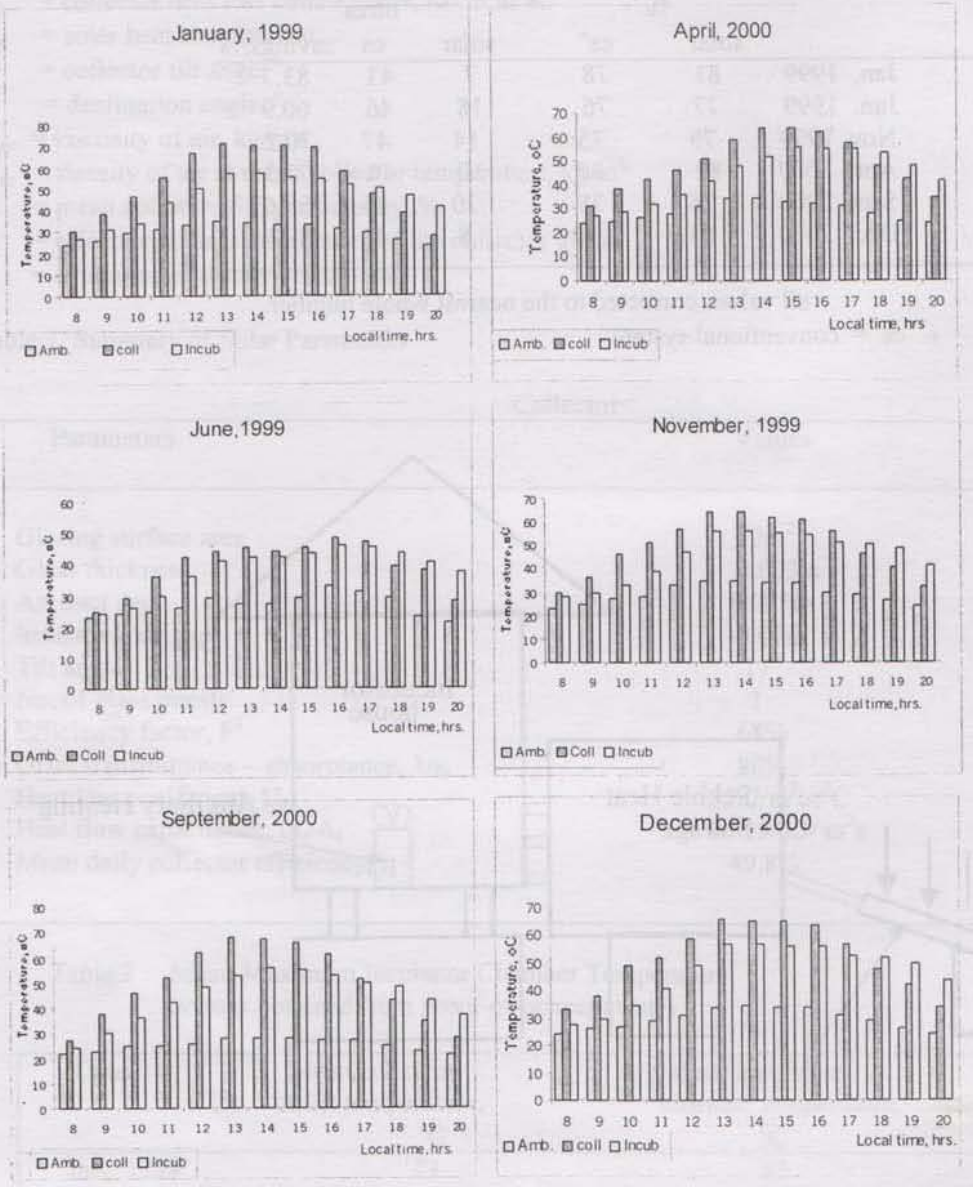


Fig. 2 Thermal performance of the egg incubator on solar arrangement for the different periods

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EFFECT OF PROCESSING FACTORS ON YIELD AND QUALITY OF MECHANICALLY EXPRESSED SOYBEAN OIL

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ABSTRACT

The effect of some processing parameters on mechanically expressed soybean oil was investigated. The process parameters investigated and their levels are moisture content (7.3, 10.2%), heating temperature (70, 80, 90^{0}C), heating time (15, 30, 45 minutes) applied pressure (28, 35, 41, 48MPa) and pressing time (15, 10 15 minutes).

The oil yield increased as the moisture content was varied form 7.3 to 10.2%, pressure from 28 up to 41 MPa, heating temperature from 70 up to 80^{0}C and heating time from 15 up to 30 minutes. However at higher values of heating temperature and time (i.e 90^{0}C and 45 minutes) there was a decrease in oil yield. The highest oil yield of 10.4% was obtained when samples at 10.2% moisture content were heated for 45 minutes at a temperature of 80^{0}C and pressed for 48MPa for 15 minutes. The colour and FFA of the oil expressed at these processing parameters is within acceptable range for crude soybean oil.

KEY WORDS

Yield, quality, mechanical expression, soybean oil

1.0 INTRODUCTION

Soybean has dominated the world oilseed production. Demand is mainly for its oil and meal (Wilcox, 1987) due to the qualities of the oil expressed form soybean seed. Soybean oil had accounted for more than one third of the world's vegetable oil production (Beauregard, 1989). About 90% of the domestic uses of soybean oil is for domestic food which include cooking and salad oils, margarine and shortening while 10% is used for non-food products (Ledesma, 1989). The major producer of soybean oil is the United States (U.S) (Nwokolo, 1996) but in Nigeria the production of soybean oil has not been on a large scale due to the limitations which reduce the rapid expansion of the use of the oil. These limitations include inadequate widespread information on the production of soybean oil and improper processing of the seeds.

In Nigeria, small and medium scale processors of vegetable oil prefer mechanical expression (oil removal using machines) to extraction (oil removal using solvents). This is due to the high cost of operation and contamination of oil in the extraction process. Mechanical expression can be achieved either by using screw press, hydraulic press, roll press etc. However the hydraulic press is preferred by the small-scale processors because of its lower operational cost even though the screw press is more efficient. In order to increase the production of soybean oil in Nigeria since adequate information on soybean oil processing is lacking, a study on the effect of processing factors on the yield and quality of soybean oil is required to provide some of the required information on soybean oil production (Khana and Hanna, 1984; Adeeko and Ajibola, 1990; Adekola, 1995).

A number of factors i.e particle size, heating temperature and time, moisture content, applied pressure and duration of pressing which have to be studied in order to achieve efficient expression of oil. This is because these processing factors are observed to be crop specific since they have different effects on different oilseeds. Size reduction which increases the area of oil bearing cells exposed to heat treatment, is necessary. Othmer and Agarwal (1955) observed that the inability to get oil from whole and half soybean indicates that the cell wall need to be broken before oil can be removed from the otherwise impervious cells. However size reduction should not be excessive as observed by Ward (1976), and Khan and Hanna (1984) as it reduces the quantity of oil expressed. Heat treatment is also essential since it reduces viscosity of oil in the oil capillaries, coagulate the protein to increase voids which allow for easier expression. It also brings the moisture content to the optimum for expression.

Researchers carried out by a number of authors including Ajibola et al (1990), Adeeko and Ajibola (1990), Sivakumaran et al (1985) have revealed that the heat treatment has a significant effect on the oil yield. An increase in heat treatment increased the oil yield of the oilseeds considered (namely peanut, groundnut and melon) however, too high heating temperatures or time resulted in a decrease in oil yield due to the hardening of the oilseed surfaces. This hardening increased the resistance to oil expression. Bongirwar et al (1977), Sivakumaran et al (1985), Pomiski et al (1970) and Ajibola (1989) also identified that each of the oilseeds considered had an optimum moisture content at which oil yield is maximum.

Fashina and Ajibola (1989) observed that an increase in the application of pressure from 10 to 20 MPa increased oil yield while a further increase to 25 MPa decreased or leveled off the oil yield for soybean oilseed. This is because an increase in pressure or its duration increased the shearing of the oil cells which allow for expression of oil. Too high pressure or too long pressing duration however eventually seals off the capillaries thus leveling off or decreasing oil yield. Therefore optimum pressure and pressing time for each oilseed has to be identified so as to achieve maximum oil yield.

The quality of the oil expressed is an important aspect of oil processing that needs monitoring since most edible vegetable oils are sold as crude oil in Nigeria. The parameters used to measure the quality of oil expressed include the Free Fatty Acid (FFA), peroxide value (PV) and the color intensity of the oil. The FFA in oil is an indication of the care and control exercised during procession and also of the freshness of the oil (Head et al, 1995). The PV is an indication of oxidative stability of the oil and therefore high PV indicates the rancidity of the oil. This study was carried out to determine the processing factors that have an effect on yield and quality of soybean oil. The processing factors considered were moisture content, heating temperature and heating time, applied pressure and duration of pressing and the quality parameters considered were color, FFA and PV.

2.0 MATERIALS AND METHODS.

The soybean seeds were cleaned manually and put in pack of 400g. Each pack of 400g of soybean seeds were ground to a coarse particle size (passed through a 4.75mm sieve) using a small china mortar and pestle because of the size of each sample used. The ground samples were heated by spreading thinly on metal tray in an oven at a preset temperature (which was verified using a thermometer). The samples were heated at temperature levels of 70, 80 and 90^{0}C and time combinations of 15,30 and 45 minutes. The samples were then placed in the pressing chamber. A hydraulic press was used to apply different pressures of 28, 35, 41 and 48MPa at different pressing times of 5, 10 and 15 minutes in order to express the oil. The moisture content of the soybean seed used was 7.3 and 10.2% (wet basis) while each experiment had two replicates.

2.1 Tests and Analysis

A set of standard sieves were used to determine the particle size analysis in accordance with ASAE (1989) standard S319. The moisture content was determined by the AOAC (1984) standard of heating in an oven a temperature 130^{0}C for 6 hours. The oil/fat content of the unexpressed and expressed samples were determined using the Soxhlet extraction method. The FFA and PV were determined using the titration method while the Munsell color charts were used for color grading.

3.0 RESULTS AND DISCUSSION

The oil yield from the samples at moisture contents of 7.3 and 10.2% (wet basis) subjected different processing variable are shown in Tables 1 and 2.

Table 1 : Oil yield obtained from soybean seeds of 7.3 % m.c. and pressed for 15 minutes

	Heating Temp(^{0}C)	Heating time (mins)		
		15	30	45
28	70	5.40	5.65	5.33
	80	5.84	6.03	4.88
	90	4.69	6.26	6.32
35	70	5.66	6.80	6.05
	80	6.02	7.51	6.34
	90	5.66	6.54	6.03
41	70	7.31	8.71	8.49
	80	6.66	7.90	7.61
	90	6.36	6.91	6.41
48	70	7.06	7.15	7.32
	80	6.80	8.22	8.02
	90	7.04	8.13	9.22

Table 2: Oil yield obtained form soybean seeds of 10.2% m.c. and pressed for 15 minutes.

	Heating Temp(^{0}C)	Heating time (mins)		
		15	30	45
28	70	5.79	6.02	5.73
	80	6.45	6.11	5.21
	90	6.80	4.01	4.38
35	70	8.40	7.36	8.49
	80	6.58	6.47	7.17
	90	6.91	4.58	4.68
41	70	9.28	8.48	9.38
	80	8.36	6.97	8.63
	90	6.73	5.40	6.19
48	70	8.24	8.64	9.10
	80	8.88	8.01	10.04
	90	7.79	8.35	9.03

The oil yield from soybean seeds of 10.2% M.C. was generally higher than that for samples of 7.3% M.C with a few exceptions. This may be attributed to the fact that the higher the initial moisture content, the higher the moisture removed from the oilseed during heating. The moisture removal and the coalgulation of protein (as a result of heat treatment) creates bigger voids which enables freer oil flow during expression (Adeeko and Ajibola, 1990). Also as moisture is lost, the sample becomes hardened which reduces the flow of the oil out of the seed. This takes place faster in soybeans seed with 7.3% m.c. this can also be responsible for the decreases in oil yield for soybean seeds at 7.3% m.c.

An increase in pressure applied generally from 28 to 41MPa increased the oil yield but a further increase to 48MPa in most cases resulted in a decrease in yield (Tables 1 and 2). This increase in yield may be due to the shearing of oil capillaries during the application of pressure. The decrease in oil yield at high pressure is similar to the observation of Ward (1976) and Adeeko and Ajibola (1990) who observed that increasing the pressure applied beyond an optimum value will eventually seal the capillaries due to the increasing narrowing of the oil capillaries as the pressure increases. The oil yield also increased with an increase in pressing time, and about 80% of the oil was expressed during the first minutes with the remaining being expressed during the next 10 minutes.

The oil yield was also observed to increase with heating temperature generally. An increase in temperature from 70 to 80°C increased the oil yield from 5.66 to 6.02% for samples of 7.3% m.c heated at 15 minutes and pressed at 35 MPa but a further increase to 90°C reduced the oil yield to 5.66%. This increase may be due to the fact that hardening of the surface of samples occur more easily at higher heating temperatures, or time due to greater application of heat. This hardening resist the flow of oil out of the samples. (Table 1). From the two tables the effect of heating time on oil yield was observed generally to be that an increase in heating time resulted in an increase in yield. . However at a temperature of 80°C, an increase in heating time beyond 30 minute resulted in a decrease in oil yield. This increase in yield due to increase in temperature or time is because when samples are heated, coagulation of protein, reduction of oil viscosity and adjustment of moisture content through moisture loss occur.

The protein coagulation and reduction in oil viscosity increases oil yield since they allow the oil to flow freely. The moisture loss however when substantial enough (especially at high heating temperature on time) causes the hardening of the surface of the sample thus resisting the application of pressure. This causes a reduction in oil yield (Tables 1 and 2) and it implies that high heating temperature and times should be avoided since it has an implication on the energy use and cost in soybean oil production.

3.1 Effect of processing factors on oil quality

The processing factors were observed to have a significant effect on oil quality. The colour intensity of oil increased as the heating temperature and time increased (Table 3)

Table 3: Colour oil obtained from soybean seeds

Moisture content	Heating time (mins)	Heating Temperature (^{0}C)		
		70	80	90
7.3%	15	Light yellow	Light yellow	Light yellow
	30	Light yellow	Pale yellow	Pale yellow
	45	Pale yellow	Pale yellow	Yellow
10.2	15	Light yellow	Pale yellow	Pale yellow
	30	Light yellow	Light yellow	Pale yellow
	45	Pale yellow	Yellow	Yellow

Where in order of increasing colour intensity: Light yellow, Pale yellow, Yellow.

Feather (1977) observed that colour formation from carbohydrates in food occurred when there is loss of one or more molecules of water from carbohydrates. This implies that the increase in colour intensity as the heating temperature and time increase is due to loss of moisture which occurs. The colour of the expressed oil darkened gradually from light yellow to pale yellow and then to yellow as the temperature and time increased. From Table 3, a yellow coloured crude oil was obtained from a heating time of 45 minutes and a temperature of 90^{0}C (the highest temperature and time). This yellow colour of crude oil is acceptable for good quality crude oil (Rossell and Prichard, 1991). This is because dark coloured oils are undesirable since it will need special refining which increase the cost of production of the refined oil. Soybean seeds of higher moisture contents gave darker colour of oils. This is cause

more molecules of water will be lost heat treatment than in the case of soybean seeds of lower moisture content.

The Free Fatty Acid value increased with an increase in heating temperature and time (Table 4). This is similar to the observation of Adecko and Ajibola (1990) where an increase in heating temperature and time for groundnut also increased the FFA value.

Table 4: FFA value of oils obtained from expression of soybean seed

Moisture content (%w.b)	Heating time (mins)	Heating Temperature (^{0}C)		
		70	80	90
7.3%	15	0.88	0.95	1.23
	30	0.95	0.98	1.44
	45	1.09	1.23	1.57
10.2	15	0.71	0.84	1.16
	30	0.96	1.12	1.40
	45	1.14	1.21	1.57

The FFA is the Fatty Acid present in the oil that are not "held" unto a glycerin molecule. An increase in heat application increases the lipase activity, which increase the breaking of the bond between fatty acids and glycerin molecules and this increase the range of FFA. The range of FFA value from Table 4 (i.e 0.71 – 1.57) is generally below the standared level for crude soybean oil which is 1.5% (Pryde et al, 1985). High levels of FFA should be avoided since it leads to excessive smoking and unsatisfactory oil flavour. A temperature of 90^{0}C and time of 45 minutes gave a high FFA value of 1.57% and this implies that high temperatures and times should be avoided.

The variation in processing factors also had an effect on the peroxide value (PV) as indicated in Table 5. An increase in heating temperature and time also increased the PV.

Table 5: PV for oil obtained from expression of soybean seeds.

Moisture content	Heating time (mins)	Heating Temperature (^{0}C)		
		70	80	90
7.5%	15	25.5	27.6	31.4
	30	37.3	41.1	44.3
	45	68.4	70.2	82.7
10.2	15	22.0	26.9	28.6
	30	30.4	31.4	40.0
	45	62.7	74.2	80.8

The PV is an index of the amount of oxidation for unheated fats and also an indication of its oxidative stability. The high level of PV for soybean oil is because it is unstable to oxidation due to its linolenic acid content which results in faster oxidation than other fatty acids. Lawson (1985) also observed that peroxides develop to a certain extent during processing depending on heating temperature and time and these peroxides increase with increase in heating temperature and time.

4.0 CONCLUSION

The processing factors investigated have been identified as having a significant effect on the oil expressed from soybean seeds. Generally the oil yield increased with an increase in pressure from 28 to 41MPa while a further increase to 48 MPa reduced the oil yield. The oil yield also increased generally with an increase in pressing time with majority of the oil expressed in the first five minutes. An increase in heating temperature and time also increased the oil yield however at combinations of high heating

ıperatures and time, a decrease in yield was obtained. The increase in heating temperature and time ulted in an increase in colour intensity, FFA and PV of the soybean oil expressed. Therefore the cessing factors have a significant effect on the yield and quality of soybean oil produced and as such d to be considered or monitored effectively during soybean oil production.

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INVESTIGATION OF FARM ACCIDENTS IN NIGERIA. PART 1: - Federal Capital Territory, and Kaduna, Kwara and Niger States

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ABSTRACT

Investigative Survey Research Approach (ISRA) was used to establish the types, causes and cost of farm accidents on selected mechanized farms in Nigeria. This paper is a report of the first stage of the work, which covers Niger, Kaduna, and Kwara States and the Federal Capital Territory. The data collection instrument was a questionnaire made up of parts A and B with 12 and 25 questions respectively. Part A of the questionnaire addresses demographic variables and part B addresses issues linked directly with types, causes and cost of accidents. Results show that 82.5% of accident victims are male. About 74% of accident victims were aged between 20 and 30 years. Up to 45.33% of minor accidents resulted in slight damage to equipment. Similarly, 30.67% of accidents resulted in substantial time loss, while 21.33% and about 3% of accidents resulted in medical attention and loss of lives respectivefully. No attempt was made to quantify in monetary terms the cost of each accident, as there was dearth of information. The results obtained in this work are in agreement with the discoveries in previous studies outside Nigeria. Poor record keeping characterized most of the establishments surveyed.

KEYWORDS:
farm, accidents, tractors, machinery, survey, Nigeria

1.0 INTRODUTION

Background

Investigating accidents occurring in the farm has been a concern of farmers and researchers for many years in the developed world (Yisa, 1995 and 1996). In recognition of the importance of farm accidents, studies were conducted to determine the source of frequent injuries in farming communities. Several investigations have been made on tractor overturning accidents in England and Wales, due to the fact that through the years from 1968 to 1978, there was a continuous upward trend in the number of accidents as emphasized by the survey of the Health and Safety Executives (HSE) in Britain Hunter and Owen (1985) conducted a comprehensive study of tractor overturning accidents on slopes. The work shows the serious consequences of accidents for the farmers. Most farm accidents resulting from farm mechanics activities may be prevented by the development of safe habits and following the general safety precautions.

Causes of Farm Accidents

A number of factors could be responsible for farm accidents. These include environmental factors, exceeding the capability of the equipment, improper operation of equipment and human factors. Of all these factors, only environmental factors are not directly controllable by man. Such environmental factors are topography, vegetation, shape and size of farms, rainfall, wildfire etc. A tractor or equipment operated on a slope beyond its static stability limit (slope steep enough to cause at least one of its wheels to lift off the ground) is a typical example of how the capability of an equipment could be exceeded. Operating a tractor or any other equipment without proper maintenance and without proper hitching of implement by

implement by an operator constitute improper operation of the equipment. Accidents occurring as a result of human factors seem to be more in number than those occurring as a result of other factors. Driving a tractor at night without light is a careless behavior.

Fire, chemicals, noise and explosions cause many deaths and destruction of property. Numerous explosions have occurred in farm shops because gasoline was used for cleaning. Also, welding without necessary precaution may cause explosion. It is paramount to note that there are more accidental deaths in agriculture than in any other major industry, Farm mechanization activities are the source of the majority of accidents in farming (Jain and Rai, 1980). Accidents cause loss of lives, money and time.

2.0 MATERIALS AND METHODS

A wide range of accidents is possible on a typical Nigerian farm. They range from snakebites, wildfire, flood disaster, poisoning from agro-chemicals to accidents involving machinery (both field and workshop). Due to the enormity of work and resources that would be required to conduct a research to cover all spheres of farm accidents in Nigeria, this research was limited mainly to accidents occurring on mechanized farms. Similarly, it was decided that due to the size of the country, Nigeria, it would be difficult to attempt to cover the whole country at a go. The area represents a major agricultural region of the country. It comprises of Federal Capital Territory, Kaduna, Kwara and Niger states. Through a preliminary inuquire a list of the mechanized farms in each of the states under study was obtained from the respective ministries of agriculture. For each state and Federal Capital Territory, a third of the total number of mechanized frams were randomly selected for study using cards. Cards bearing the names of the mechanized frams were placed in a box made for the purpose. Drawing without replacement was then conducted. The Investigative Survey Research Approach (ISRA) was adopted. Investigative Survey Research Approach is a research method used essentially in developing countries where literacy level is low. In Nigeria for example, many of those who operate agricultural equipment may not have had more than elementary education. Therefore, such a person would normally not be capable of completing a questionnaire, which is on a highly technical subject. For this reason, research work involving survey of farming population is done via on-the-spot interview and completion of questionnaire (investigative). Under this method, questionnaire is taken to the sites of interest by the researcher or his representative who must have been trained for the job. The questions are then read to the respondent, if need be additional explanation of the questions is given in the local language. Where physical evidences of accidents exist, they are noted for further analysis. The survey covers a period of five years (1993 – 1997 inclusive).

A two-part questionnaire was designed for the study. The first part was to obtain the background information with regards to location and name of establishment, machinery and tractor types and number, and establishment ownership. The second part was more detailed. It was meant to provide a description of each accident in terms of type, cause and cost.

3.0 RESULTS AND DISCUSSION

Farm accident is defined as anything unpleasant or damaging, which happens unexpectedly or by chance that results in injury, loss of life, property damage, time loss and intangible loss as a result of operation of farm machinery. Similarly, all incidental occurrences related to agricultural activities such as fire outbreak, chemical explosion on the farm or at workshop, snake-bite, bees invasion, drowning in a farm dam etc. are regarded as farm accidents. The data obtained were analyzed in two parts. General characteristics of respondents by demographic properties were first considered. Of interest were gender, age, and educational qualifications of respondents or victims on one hand and establishment ownership and tractor type on the other. This first section was based on the first part of the questionnaire. The second section relates to the description of farm accidents, these include causes, types and cost of accidents, analysis of the extent of damage. Some case studies were also considered. A total of 54 mechanised farms were investigated.

Inventory of tractors, other machinery and accidents

Table 1 shows a summary of tractor and equipment inventory in the area under study. A total of 396 tractors were available in the farms surveyed. Other equipment, including ploughs, harrows, ridgers etc. were 475. Of the 75 farm related accidents recorded for the area, 29 involved tractors giving a ratio of roughly 1 accident per 14 tractors. This ratio is rather high and unparalleled in available literature on the subject.

Table 1. Inventory of tractors and machinery in the area under survey

	Federal Capital Territory	Kaduna	Kwara	Niger	Total
Tractors	36	106	108	144	396
Other equipment	18	115	123	219	475
No. of accidents with tractors	3	8	8	10	29
Total no. of accidents	4	16	24	31	75

General characteristics of respondents by demographic variables.

Table 2 shows sex distribution of victims of farm accident. Apart from Kwara State, there were more male victims than their female counterpart. On the whole, 82.5% of victims of farm accidents in the study area were male worhers while the female workers constituted the balance of 17.5 %. This outcome was expected since more men are involved in farm machinery operation than women. Until recently the general belief in this part of the world was that farm machinery operation was an entirely male affair.

Table 2. Sex distribution of accident victims in percentage

Sex	Federal Capital Territory		Kaduna		Kwara		Niger		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Male	1	25	14	87.5	21	87.5	25	80	61	82.5
Female	3	75	2	12.5	3	12.5	6	20	14	17.5
Total	4	100	16	100	24	100	31	100	75	100

About 40% of accident victims were aged between 21-30 years, another 34% were aged between 31-40 years, and only about 25% of the victims were aged either above 40 years or below 20 years, Table 3. These percentages show that majority of the people involved in accidents are young working class people. This certainly represents a great loss to the establishments where they occured and the nation as a whole. Seventy six percent of the accidents occurred in the government owned establishments and 24% accidents occurred in private owned establishments, Table 4. No jointly owned establishments were found in the area.

Analysis of Farm Accidents

The survey revealed that accidents on the farms are of different types in terms of equipment or machinery (if any) involved. The accident data were therefore categorized into five types: those involving tractor failure, implement failure, tractor – implement system failure, tools failure and accidents of environmental nature, Table 5.

Table 3. Age distribution of accident victims in percentage

Age of victims	Federal Capital Territory		Kaduna		Kwara		Niger		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
<20	-	-	2	12.5	7	28.6	4	12.9	13	17.33
20-30	4	100	9	56.25	9	38.2	8	25.8	30	40.23
31-40	-	-	5	31.25	8	33.2	13	41.9	26	34.44
>40	-	-	-	-	-	-	6	19.4	6	8.00
Total	4	100	16	100	24	100	31	100	75	100

Table 4. Distribution of establishment ownership

Owner-ship of Est.	Federal Capital Territory		Kaduna		Kwara		Niger		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Private	-	-	5	33.3	4	19.1	4	26.7	13	24
Govern ment	3	100	10	66.7	17	80.9	11	73.3	41	76
Total	3	100	15	100	21	100	15	100	54	100

Table 5. Distribution of cost of accidents

Effect of accidents	Federal Capital Territory		Kaduna		Kwara		Niger		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Time loss	1	25	4	25	8	33.33	10	32.36	23	30.67
Property damage	-		6	37.5	15	62.5	13	41.94	34	45.33
Medical attention	3	75	5	31.25	1	4.17	7	22.5	16	21.33
Intangible loss	-	-	1	12.5	-	-	1	3.23	2	2.67
Total	4	100	16	100	24	100	31	100	75	100

Similarly, many factors were presumed to be responsible for the accidents, even though it is clear that accidents are hardly caused by just a single factor but a combination of factors. It is, however, possible to state, which of the factors had a greater chance of contributing to the occurrence of a particular accident situation. The following factors were found in specific cases to have had that chance. They are; environmental factors (electricity hazard, noise, snake bite, insect invasion, fire outbreak), human factors (poorly trained operator, non- compliance with safety precautions, carelessness on the part of operator), improper operation of equipment (poor hitching of equipment to the tractor, poor maintenance culture); exceeding the limitation of equipment (operation on very steep slopes), Table 6.

Cost of accidents is most appropriately expressed in monetary terms. However, due to lack of adequate data as a result of poor documentation of accidents at the establishments surveyed it was not possible to do this. In place of this, the accidents were classified into those that (1) resulted in time loss (2) Property damage, (3) Medical attention (4) Intangible loss (loss of life), Table 7.

Types of accidents

Table 5 shows an overview of the nature of the accidents recorded in the area under survey. Environmental related accidents were more in all the states, accounting for 28 (37.33%) of the 75 accidents recorded. Twenty four percent of the accidents were tractor failure type. The remaining accidents involved implements failure (16%), tractor–implement system failure about 19% and tools failure 4%.

Causes of Accidents

Environmental factors, human factors, and improper operation of equipment and exceeding the limitation of equipment could cause accidents on the farm. It could be argued that apart from environmental factors, other factors are one and the same because they all have an element of human involvement. However, in order to differentiate between those accidents caused by out right careless behavior and those caused by other forms of human errors, this classification into five causes becomes imperative, Table 6. For instance, improper operation of equipment was found to have been caused in 11 cases due to ignorance or lack of resources to keep the equipment technically fit for operation, but the operators were under instruction of their superiors to use the equipment in spite of their poor state. Similarly, 30 accidents were caused either as a result of over loading, driving on very steep slopes or driving over ditches. These accidents are classified as having been caused by exceeding the limitation of the equipment. Environmental factors were responsible for 24 accidents or 32% of all accidents while as analyzed above, other factors were responsible for the balance of 51 accidents or 68% of total.

Table 6. Accident types

Accident types	Federal Capital Territory		Kaduna		Kwara		Niger		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Tractor failure	1	25	2	12.5	9	37.5	6	19.36	18	24
Implement failure	1	25	2	12.5	5	20.83	4	12.90	12	16
Tractor-implement system failure	-	-	5	31.25	1	4.17	8	25.81	14	18.67
Tools failure	1	25	-	-	-	-	2	6.45	3	4
Environ. Conditions	1	25	7	43.75	9	37.5	11	35.48	28	37.33
Total	4	100	16	100	24	100	31	100	75	100

Cost of Accidents

During the survey and interviews conducted, it was discovered that the establishments under study never kept proper records of the cost of accidents in monetary terms. There was therefore, the problem of how to document this important aspect of the study. It was resolved that accidents be classified in terms of those resulting in time loss, property damage, medical attention and intangible loss. Here, number of accidents in the various groups was noted, and the percentages found. Table 7. Intangible losses refer to deaths. Based on this classification, the highest number of accidents (about 45%) resulted in property damage. Other accidents resulted in time loss (30.67%), medical attention (21.33%) and deaths (2.67%). Table 7.

Table 7. Causes of accidents

Causes of accidents	Federal Capital Territory		Kaduna		Kwara		Niger		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Environ. factors	1	25	4	25	9	37.5	10	32.26	24	32
Human factors	-	-	2	12.5	6	25	2	6.45	10	13.33
Improper operat. of equip.	1	25	1	6.25	9	37.5	-	-	11	14.66
Exceeding the limitation of equip.	2	50	9	56.25	-	-	19	61.3	30	40
Total	4	100	16	100	24	100	31	100	75	100

Case studies

1. A two-wheel drive tractor returning from the farm in the night entered a major road without lights or indicators. As a result of this an oncoming 18-wheel truck loaded with unbagged fertilizer collided with the tractor. The operator of this tractor died on the spot while two other farmers on the tractor were hospitalized over a long period of time. The tractor was broken into three parts and the 18-wheel truck overturned sideways. This accident represents a typical example of how carelessness leads to accidents. If the lights were on, this accident could have been avoided, the tractor, fertilizer and time would have been saved.

2. An operator, after finishing ploughing a certain portion of a field, parked the tractor – plough combination by the road on an inclined plane without engaging the hand brake. As he attempted to jump down from the tractor, his trousers caught the selector lever and freed the tractor. He hanged on as the tractor freely descended the slope. Seriously, injured when the tractor – plough system was brought to a halt at the end of the slope when it hit a tree, he was rushed to the hospital for treatment. This accident could have been avoided, if the operator had been a little more careful.

3. A crawler tractor was being used to clear a virgin piece of land for sugar cane plantation. The tractor even though had a roll-over-protective structure (ROPS) never had a safety cabin. As clearing progressed, he entered bees' colony. Angered by the presence of the intruder the bees descended on the operator and stung him to death. This accident was caused by environmental factor (bees).

4.0 CONCLUSION

This study has revealed that the major cause of farm accidents on selected mechanised farms in Federal Capital Territory, Kaduna, Kwara States and Niger is environmental and human factors. Most of the people involved in farm accidents weere male aged, between 21 - 30 years. Human factors were responsible for over 50% percent of the accidents in the study area.

Niger State has the highest number of equipment and tractors and also highest number of accidents. A number of problems were encountered when administering the questionnaire. These are lack of proper and adequate information in some establishments, poor record keeping. All establishments visited had no proper record of cases of farm accidents. This might be the major cause of the lack of cooperation and cold attitude of some of the establishments towards the exercise. Adequate training and education of our operators would reduce the occurrence of accidents on our farms. Also, proper documentation of accident cases would be useful in training of operators and other farm workers.

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USING DIMENSIONLESS PREDICTION TERMS TO DESCRIBE CORN (*Zea mays* L.) PERFORMANCE AS AFFECTED BY TILLAGE TREATMENTS

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ABSTRACT

A look at the existing crop yield models reveals that none of these models have been apt enough to depict the crop yield completely and the prediction accuracy of tillage system effects on crop performance has remained a perpetual challenge for agricultural enterprise. Dimensionless prediction terms have been used to describe corn performance as affected by tillage treatments. Results showed that corn grain yields predicted from the model were reasonably close to the measured values. None of the estimations resulted in any appreciable bias. The variance of estimated mean differences (VERMDIFF), mean square error (MSE) and average predicted estimation of variables of mean differences (AVEPVAR) are 0.098, 0.101 and 0.096 respectively. Tillage treatments significantly affected ($P \leq 0.01$) the soil temperature, soil strength and soil moisture content. The most rapid seedling emergence pattern and highest corn yield were obtained in soil temperatures that averaged 30^{o}C at seed level. There was a negative linear correlation between the soil strength and corn grain yield.

KEYWORDS:
Dimensionless prediction terms; corn performance; tillage treatment

1. INTRODUCTION

In Nigeria, there are many examples of unsuccessful farm projects which failed as a result of inefficient tillage systems and inappropriate farm equipment. Tillage is the most fundamental and essential part of cropping system because it forms an important factor in the optimum growth and yield of crop. Many tillage systems are used in the quest for conservation of land and water, retention of soil nutrients within their target site, deep soil profile modification for increased root exploration and increased crop yield. Only those tillage systems which are fully adapted to the prevailing climatic and environmental conditions will find acceptance by the vast majority of farmers.

The proper utilization of tillage system for crop production has never held a more prominent position on the farm than in these present times because the influence and effects of tillage system on the world food supply are extremely important. Tillage research started from the concept that tillage improves soil fertility and therefore crop yields (Boone, 1988) and that tillage is an important aspect of crop production process (Baeumer and Bakermans, 1973; Davies and Cannell, 1975; Lal, 1986). Tillage research has been frequently used in solving problems that will improve the tillage system in place. However, attempts to transfer tillage system from one site to another have often failed because the link between tillage tool action, subsequent soil conditions, fluxes of soil moisture, climatic and management factors have not been fully explored and understood.

Earlier studies (Luth and Wismer, 1971; Wismer and Luth, 1972; Freitag *et al.*, 1977 and Evans *et al.*, 1985), used scale modeling and dimensional techniques to model soil-machine interactions. Researchers (Anazodo, 1981; Braide, 1981; Makanjola, 1983; Oni, 1983) have worked extensively on the

design and development of tillage tools and the effects of tillage and management practices on crop yield have been studied (Ojeniyi, 1986; Maurya, 1993). However, prediction accuracy of tillage system effects on crop performance has remained a perpetual challenge for the agricultural enterprise.

The main objective of this research is to use dimensionless prediction terms to describe corn performance as affected by tillage treatments. Specific objectives include evaluation of the effects of tillage treatments on soil temperature, soil strength and soil moisture content. These three factors have seldom been evaluated in the same study using the same soil.

1.1 Theory

Dimensional analysis was used to simplify the prediction equation for soil-machine system. The variables considered in the resulting prediction equation are presented in Table 1.

Table 1: Variables and their corresponding dimensions.

Variable	Symbol	Unit	Dimensions (M, L, T, Symbol)
Crop yield	Y	tha^{-1}	ML^{-2}
Soil resistance to penetrometer pressure	C	MPa	$ML^{-1}T^{-2}$
Depth of soil cut	D	cm	L
Soil dry bulk density	d	kgm^{-3}	ML^{-3}
Nitrogen rate	N	$kgha^{-1}$	ML^{-2}
Time input	I	hha^{-1}	TL^{-2}

Six pertinent variables are involved in the model development. In general, the relationship between the measurable quantities (the secondary quantities) and the appropriate quantities (the primary quantities) may be expressed as:

$$Y = F(C, D, \gamma d, N, I) \quad 1$$

where:

Y = crop yield, t / ha
C = soil resistance to penetrometer pressure, Mpa
D = depth of soil cut, cm
γ d = soil dry bulk density, kgm^{-3}
N = nitrogen rate, kg / ha
I = time input, h / ha

$$\phi\left(\frac{Y}{N}, \frac{\gamma dD}{N}, \frac{CN^2I^2}{[\gamma d^2]^3}\right) = 0 \quad 2$$

and

$$\frac{Y}{N} = F\left(\frac{\gamma dD}{N}, \frac{CN^2I^2}{[\gamma d^2]^3}\right) \quad 3$$

Here we have six variables and three basic dimensions: mass (M), length (L), and time (T). The Buckingham Pi Theorem states that the number of dimensionless and independent quantities required to express a relationship among the variables in any phenomenon is equal to the number of quantities involved minus the number of dimensions in which these quantitites may be measured (Buckingham, 1914; Reyleigh, 1915; Glenn, 1950). Then a set of dimensionless groups characterizing this phenomenon would be: Defining mathematical relations for these functions results in a soil-machine prediction model. Three Pi terms are required and the Equation (3) can be written as:

$$\pi_1 = F(\pi_2, \pi_3) \quad 4$$

By plotting π_1 against π_2, the relationship:

$$(\pi_1)_3 = F_1\left(\pi_2, \bar{\pi}_3\right) \quad 5$$

in which the bar denotes constant values, could be established. Similarly, a plot of π_1 against π_3 could generate the relationship:

$$(\pi_2)_2 = F_2\left(\bar{\pi}_2, \pi_3\right) \quad 6$$

$$\pi_1 = Y/N, \pi_2 = \frac{\gamma dD}{N}; \pi_3 = \frac{CN^2I^2}{(\gamma d)^3}$$

1.2 Method of Solution

If it is assumed that:

$$F(\pi_2, \pi_3) = F(\pi_2) + g(\pi_3) \quad 7$$

Then,

$$F\left(\bar{\pi}_2, \pi_3\right) = F\left(\bar{\pi}_2\right) + (\pi_3) \quad 8$$

from which,

$$g(\pi_1) = F\left(\bar{\pi}_2, \pi_3\right) - F\left(\bar{\pi}_2\right) \quad 9$$

Similarly,

$$F(\pi_2) = F\left(\pi_2, \bar{\pi}_3\right) - g\left(\bar{\pi}_3\right) \quad 10$$

Equation (7) may therefore be written as:

$$F(\pi_2,\pi_3) = F\left(\pi_2,\bar{\pi_3}\right) - g\left(\bar{\pi_3}\right) + F\left(\pi_2,\pi_3\right) - F\left(\bar{\pi_2}\right) = F(\pi_2,\pi_3) + F\left(\bar{\pi_2},\pi_3\right) - F\left(\bar{\pi_2},\bar{\pi_3}\right) \quad 11$$

Equation (11) shows that if the component equations are to be combined by addition to form the general prediction equation, a constant must be subtracted from the sum of the component equations. Hence, by solving and substituting,

$$\pi_1 = -36.022 + 0.830x10^{-3}\pi_2 + 9.330x10^{7}\pi_3 \quad 12$$

and

$$Y = -36.022N + 0.830x10^{-3}\gamma dD + 9.330x10^{7}CN^3I^2(\gamma d)^{-3} \quad 13$$

To verify the forgoing technique, an experiment was conducted.

2. DESCRIPTION OF EXPERIMENT

2.1 Site

On-farm trials were conducted at Samaru ($11^0$11'N, $07^0$38'E and 685m above sea level) in Kaduna State, Nigeria. Samaru is in the Northern Guinea savanna zone of Nigeria with an average rainfall of 1,100mm spread between May and October. The soil is classified as alfisol (Moberg and Esau, 1989).

2.2 Soil Profile

The field has a gentle slope and low water holding capacity. The soil profile is characterized generally by a sandy surface horizon underlying a horizon of clay accumulation with a weak sub-angular blocky structure and a reddish-brown to a greyish-brown colour (resembling yellowish ferallitic soils) (Pugh and King, 1952). The pedon belongs to the order of feruginous tropical soils.

2.3 Field and Laboratory Measurements

Five tillage treatments were carried out as follows: Arara ploughing followed by zig-zag harrowing and arara ridging (T1), emcot ploughing followed by zig-zag harrowing and emcot ridging (T2), mouldboard ploughing followed by disc harrowing and mouldboard ridging (T3), disc ploughing followed by disc harrowing and disc ridging (T4) and manual ridging (T5) with hand hoe, T1 and T2 were done using draught animals while T3 and T4 were carried out with tillage implements coupled to a Steyr 8045 tractor. The manual method of ridging "mimicks" the "prehistoric man's" method of ridging in the absence of any form of mechanical aid. The fertilizer nitrogen rates were: No nitrogen (No), 40kg Nha^{-1} (N1), 80kg Nha^{-1}(N2) and 120kg Nha^{-1} (N3) while the two planting methods used were manual planting (P1) and mechanicai planting (P2) using corn (*Zea mays* L.) as test crop.

Fifteen soil core samples (4.2cm wide x 50cm long each) were taken with auger into an air-tight polyethylene and carried to the soil laboratory of Soil Science Department, Ahmadu Bello University, Zaria, for the determination of soil physical and chemical characteristics using the methods described by Blakemore *et al.* (1972).

Soil temperatures were measured with water proof, copper constanton thermocouples buried 10cm, 20cm and 30cm deep in the crop rows, and replicated at four locations within each tillage treatment. Temperatures were also recorded daily at 8.00h and 16.00h using a Campbell Scientific CR-5 multi-channel data logger (Campbell Scientific Inc. Logan, UT)* as described by Black (1970).

*Trade and company names are included for the benefit of the reader and do not imply endorsement by the company.

It was equipped with an S250 relay scanner. Soil moisture contents were measured in 5cm increament to a maximum soil depth of 30cm by neutron scattering technique at 30, 60 and 90 days after corn seedling emergence. One neutron access tube was randomly placed in the center row of each replication of Paymaster DR 1125 in each tillage treatment (Gerik and Morrison, 1984). Cone index (soil strength) was measured with a cone penetrometer of a 13-mm diameter cone base, a 30-degree cone angle mounted on a relieved shaft and driven at approximately $0.03ms^{-1}$ (Anderson *et al.*, 1980). The average cone index value were determined from 15 readings that were recorded at each 5.0cm increment to a depth of 30cm. These measurements were made after corn planting and numerical constants were fixed using the method described by Glenn (1950).

2.4 Model Testing

The measured values from a number of field experiments were compared with predicted values by linear regression analysis. The predictive capability of the developed model was tested against the experiments used to derive some of the functional relationships in the model. Testing on these data examines the vigor with which the model has integrated the functional relationships.

For each observed and predicted value, BIAS, variance of estimated mean differences (VARMDIFF), mean squared error (MSE), and average predicted estimation variances of mean differences (AVEPVAR) were estimated using the statistics listed in Table 2. They were computed to judge the model performance. The statistic VARMDIFF describes the precision, i.e., the random fluctuations from sample to sample, and the statistic BIAS reveals whether a methods is prone to systematic errors. The MSE measures the overall accuracy.

Table 2: Diagnostic statistics

Formula	Comment
$BIAS \quad \overset{\pi}{\Delta z} - \Delta Z = \frac{1}{70}\sum_{i=1}^{70} \overset{\pi}{\Delta zi} - \Delta z$	Bias of estimation method
$VARMDIFF = \frac{1}{70}\sum_{i=1}^{70}\left(\Delta Zi - \overset{\pi}{\Delta Z}\right)^2$	Variance of estimated mean differences
$MSE = (BIAS)^2 + VARMDIFF$	Mean of squared deviation between estimated mean differences and true difference (mean squared error)
$AVEPVAR = \frac{1}{70}\sum_{i=1}^{70}\sigma^2\left(\overset{\pi}{\Delta Zi}\right)$	Average predicted estimation variances mean of differences

2.5 Experimental Design

The treatments were randomly assigned in a strip-split-plot design with five tillage treatments (T1, T2, T3, T4 and T5) as horizontal treatments, four nitrogen rates (No, N1, N2, and N3) as vertical treatments and two planting methods (P1 and P2) as sub-plot treatments in four replications. Each plot size was 4m wide x 5m long.

2.6 Statistical Analysis

The field data obtained were analysed statistically using Analysis of Variance (ANOVA) technique. All regression analysis were conducted by using the General Linear Models (GLM) procedure (Statistical Analysis System (SAS) Institute Inc., 1989).

3. RESULTS AND DISCUSSION

3.1 Climatic Condition

The rainfall during the 1997-1999 cropping seasons varied from 1079 to 1239 mm with air temperature ranging from 24 - 35°C as shown in Table 3. Rainfall distribution was poor in 1997, pericularly in May and July. The crops were stressed during seedling emergence and grain fill stages. Much of the rainfall in August, 1997 occurred late and did not help the crop. Though, the annual rainfall in 1997 was nearly identical to that of 1999, distribution pattern was better in 1999 than 1997 resulting in the high maize grain yield in 1999.

Table 3: Climatic conditions during the 1997-1999 cropping seasons at Samaru, Nigeria.

Climatic condition	Range	Mean[a]	CV(%)[b]
Precipitation, mm	1078.5-1239.2	1123.4	1.75
Air temperature, °C	24.2-35.0	32.0	4.93
Relative humidity, %	62.0-82.8	75.8	1.72
Atmospheric pressure, mmHg	745.0-759.0	752.0	2.25

[a]Each value is a mean of five single measurements, [b]CV = coefficient of variation
Source: Agro-meteorological Service Unit, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.

3.2 Soil Condition

The physical and chemical characteristics of soil samples are shown in Table 4. The soil texture varied from loamy sand to sandy clay loam. The loamy sand consisted mostly sand but with sufficient clay to give slight plasticity and cohesion when moist while the sandy clay loam consisted of sufficient clay to be distinctly stickly when moist, and hard when dried. The soil profile indicates low fertility status.

The total nitrogen varied from 0.04 to maximum value of 0.12 percent. Soil pH tends to decrease with depth and base saturation ranged from moderate (41-58%) to high (61-79%). Since the water retention capacity of the soil is low (sand is between 60 to 70%, w/w) and its structure is poor in the tilled layer, the soil dry bulk density tends to rise rapidly after tillage operation thereby impeding root development and plant growth.

3.3 Yield Model

The corn yield model developed in this study quantifies our understanding of soil-tillage tool-environment, interactions in a physically sensible manner. The model is suitable for use in studies of potential corn yield and production risks. The model predicted the outcomes from experiments reasonably well. From the predicted and observed values, the BIAS, VARMDIFF, MSE and AVEPVAR were 0.056, 0.098, 0.101 and 0.096 respectively. The ratio between the AVEPVAR and VARMDIFF is 0,980 and the ratio between AVEPVAR and MSE is 0.951 which are close to 1.0. These indicate that the precision of the model is high (accurate). None of the estimations resulted in any appreciable bias and there was no clear difference between the predicted and the observed values. The maximum ratio between the squared bias and the mean squared error was 3.1%, demonstrating that systematic deviations were virtually absent.

3.4 Soil Temperature

The temperatures of the soil in the seed zone were generally high during day periods. This is probably because rainy seasons at Samaru, Nigeria, are characterised by warm days and cool nights along with short warm-up periods that usually occur before unpredictable heavy rainfall. Soil temperature was significantly affected ($P \leq 0.01$) by tillage treatment at 0-10cm and 10-20cm soil depths investigated

(Table 5). However, the interaction of tillage treatment x planting methods did not show any significant effect ($P \leq 0.05$) on soil temperature at 16.00h on 0-10cm and 10-20cm soil depths. Soil temperatures were lower in shallow tilled plots of T1 and T2 than in deep tilled plots of T3, T4 and T5. As result of the lower mean daily soil temperatures in shallow tilled plots of T1 and T2, crop development was generally delayed. Similar results were reported by Farazdaghi *et al.* (1986). The most rapid seedling emergemce pattern and highest corn grain yield were obtained in soil temperatures that average 30°C at seed level. This result indicates that the average daily soil temperature could be used as an index of monitoring and predicting corn grain yield under a wide range of temperature conditions that often occur during a cropping season.

3.5 Soil Moisture Content

The dominant effect of tillage treatment on soil moisture content was prominent throughout the 3-years (1997-1999) of field work. Tillage treatment significantly affected ($P \leq 0.01$) the soil moisture content (Table 6). The mean difference of soil moisture content among the years of investigation was statistically significant at 5% probability level. However, the interaction of year x tillage treatment x planting methods had no significant effect ($P \leq 0.05$) on soil moisture content. Deep tillage of T3, T4 and T5 treatments is the major cause of increased soil moisture content. This result is consistent with the report of Davis (1992) who stated that deep tillage increased soil water in the tilled soil.

3.6 Soil Strength

There was significant effect ($P \leq 0.01$) of tillage treatment on soil strength (Table 6). Differences in soil strength among the tillage treatments might have been due to compressive effects of subsoil and the differential in soil moisture content regime. Generally, penetration resistance reduced in 1998 and 1999 with increased maize grain yield as compared with the results obtained in 1997 which is in agreement with the earlier researchers (Carry and Evans, 1974; Cotching *et al.*, 1979 and Callebaut *et al.*, 1986) who reported low crop yield as a result of high soil strength.

4. CONCLUSIONS

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

1. The model predicted experimental data reasonably well with a fairly close agreement between the predictive and observed values.

2. None of the estimations resulted in any appreciable bias and there was no clear differences between the predicted and the observed data.

3. Although, the developed model has some limitations, it contains a useful degree of predictive skills for similar soils, treatments and climates.

4. The most rapid seedling emergence pattern and highest corn grain yield were obtained in soil temperatures that averaged 30°C at seed level.

5. Tillage treatments significantly affect ($P \leq 0.01$) the soil temperature, soil strength and soil moisture content.

6. There was a negative linear correlation between the soil strength and corn grain yield.

Table 4: Physical and chemical characteristics of soil (0-60cm depth) of the experimental site prior to the initiation of tillage treatments at Samaru, Nigeria.

Soil depth[a] (cm)	Sand	Silt	Clay	pH	Total N	Org. C	Avail. P (ppm)	Exchangeable cations				A.W.C.[b] (%)	Effective C.E.C. (meq./100 g soil)	B.C[c] (%)
	%, w/w				%, w/w			Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}			
							1997							
0-15	66	20	14	5.5	0.04	0.6	8.5	2.6	1.1	0.4	0.2	8.3	8.3	51.8
15-30	68	17	15	5.8	0.04	0.5	3.7	2.5	0.8	0.2	0.2	9.4	7.7	48.1
30-45	68	14	18	6.1	0.07	0.3	4.2	2.4	0.7	0.2	0.2	9.7	6.9	50.7
45-60	64	12	27	5.4	0.06	0.8	4.6	2.6	0.6	0.3	0.1	10.2	8.7	41.4
							1998							
0-15	64	20	16	5.2	0.04	0.6	6.2	3.2	1.3	0.4	0.2	6.0	6.5	78.5
15-30	66	17	17	5.3	0.06	0.5	5.3	3.0	1.2	0.3	0.2	8.8	6.4	73.4
30-45	68	13	19	5.4	0.05	0.7	4.9	2.4	0.8	0.2	0.1	9.5	6.0	58.3
45-60	62	10	28	6.0	0.09	0.8	5.0	3.2	0.8	0.2	0.1	11.5	9.4	45.8
							1999							
0-15	64	24	12	5.4	0.08	0.4	5.2	3.0	1.0	0.3	0.2	6.1	6.6	68.2
15-30	70	13	17	5.5	0.09	0.5	6.0	2.3	0.8	0.2	0.1	9.4	5.2	65.4
30-45	60	22	18	5.8	0.09	0.8	5.5	2.7	0.8	0.2	0.1	9.2	5.1	75.5
45-60	68	10	22	6.0	0.12	0.7	7.4	3.6	1.6	0.2	0.1	11.0	9.0	61.1

[a]Each value is a mean of five single measurements

[b]A.W.C. (%) = Available water capacity (field capacity - permanent wilting point)

[c]B.S. (%) = Base saturation = (Ca + Mg + K + Na/effective C.E.C.) x 100

Table 5: Combined analysis of variance of soil temperature at 8.00h, 0-10cm depth, 10- 20cm depth;16.00h, 0-10cm depth and 10-20cm depth data over a 3-year period (1997-1999)

Source of variation	df	Soil temperature (8.00h)		Soil temperature (16.00h)	
		0-10cm depth	10-20cm depth	0-10cm depth	10-20cm depth
Replication	3	12.222	15.903	8.222	20.424
Years (Y)	2	6.775*	0.731ns	16.265**	12.002**
Reps	6	14.997	3.526	7.920	10.458
Vertical factor (A)	3	11.700**	0.947ns	2.950ns	1.841ns
Y x A	6	0.275ns	3.854**	0.231ns	0.766ns
Rep (Y x A)	27	3.232	1.053	1.175	0.682
Horizontal factor (B)	4	54.153**	10.670**	98.083**	121.908**
A x B	12	5.917**	2.213**	1.985ns	1.379ns
Y x B	8	1.681ns	4.164**	3.921**	2.127ns
Y x A x B	24	3.633**	1.577ns	0.881ns	0.596ns
Reps (Y x A x B)	144	2.155	1.668	1.065	0.762
Subplot factor (C)	1	16.133**	2.408ns	0.675ns	3.502ns
A x C	3	0.322ns	3.458*	0.925ns	0.369ns
B x C	4	8.253**	4.476**	2.008ns	1.617ns
Y x C	2	37.608**	2.377ns	0.194ns	6.265**
A x B x C	12	1.831ns	[illegible]	[illegible]	[illegible]
Y x B x C	8	3.369**	1.695ns	7.621**	1.754ns
Y x A x B x C	30	2.983**	1.270ns	1.558*	0.456ns
Error	180	1.968	1.386	1.346	1.262
Total	479				

*, ** = significant at 0.05 and 0.01 probability levels, respectively; ns = not significant

Table 6: Combined analysis of variance of maize grain yield, soil moisture content, and soil strength data over 3-year period (1997-1999).

Source of variation	df	Variable		
		Maize grain yield	Soil moisture content	Soil strength
		<----- Mean squares and significance of F----->		
Replication	3	10.942	141.317	9.290
Years (Y)	2	14.637**	9.109*	0.658ns
Reps	6	1.376	87.074	0.578
Vertical factor (A)	3	0.256ns	55.090**	1.694ns
Y x A	6	0.031ns	13.950**	0.314ns
Rep (Y x A)	27	0.817	5.620	0.031
Horizontal factor (B)	4	37.038**	353.746**	27.424**
A x B	12	0.009ns	5.061**	0.099ns
Y x B	8	1.201ns	22.469**	2.787**
Y x A x B	24	0.193ns	5.164**	0.033ns
Reps (Y x A x B)	144	0.249	5.193	0.373
Subplot factor (C)	1	9.344**	232.966**	0.001ns
A x C	3	0.024ns	4.077**	0.038ns
B x C	4	0.129ns	1.398ns	2.158ns
Y x C	2	1.274ns	32.317**	2.611
A x B x C	12	0.021ns	2.981**	0.049ns
Y x B x C	8	0.598ns	0.832ns	1.829ns
Y x A x B x C	30	0.020ns	2.406**	0.019ns
Error	180	0.137	2.830	0.267
Total	479			

*, ** = significant at 0.05 and 0.01 probability levels, respectively; ns = not significant

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A COMPUTER ALGORITHM FOR THE DESIGN OF CENTER PIVOT SPRINKLER IRRIGATION SYSTEM.

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ABSTRACT

A computer algorithm for the design of Center Pivot Sprinkler Irrigation System is presented in this paper. The developed algorithm was validated using student – t analysis method. Input parameters such as sprinkler spacing along the lateral as well as the selected pipe diameter were varied to see their effects on the design output such as individual sprinkler discharge pressure, pressure variation along the lateral and the pressure at the pivot.The results revealed that sprinkler spacing along the lateral when singly considered does not significantly affect pressure variation along the lateral and pressure at the pivot. However, the pipe diameter significantly affected both the pressure variation along the lateral and pivot pressure at a 0.1% probability level. Pressure variation along the lateral and pressure at the pivot point increase with decrease in pipe size.

KEYWORDS

Computer – aided , Centre Pivot, Irrigation Systems

INTRODUCTION

A center pivot irrigation system consists of one sprinkler lateral that rotates about a fixed point where water is introduced into the system. The fixed end of the lateral, called the "pivot point" is connected to the water supply. The lateral consists of a series of span ranging in length from 30m to 75m. Each span is carried about 3m above the ground by a drive unit, an "A -Frame" tower supported on wheels propelled by electric or hydraulic motors (Anon, 1989; Schwab et al; 1993). The length of center pivot lateral pipe may vary from 61 to 792.5m (Addink et al 1976). Center pivot have high irrigation efficiency when adapted to crops, soil and climate conditions and when used with proper irrigation management practices (Pair et al., 1973). The sprinklers may have a constant spacing or the distance between sprinkler may vary (Kelso and Jarret, 1978). In a uniform-spacing impact sprinkler arrangement, a uniform application depth is distributed by using higher discharge sprinkler with increasing distances from the pivot. Center pivot systems operate best on soils with high infiltration rates that absorb water at the point of impact. The size of a particular center pivot lateral is most often chosen on the basis of economics.

The rate water is applied to the soil by a center pivot system varies from a low near the pivot to very high at the end of the lateral. The depth of water applied by a center pivot system depends upon the application rate and the speed of rotation. When the application rate is held constant, then the application depth is increased as the speed of rotation is decreased (Pair et al. , 1973). James (1982) developed a mathematical model for estimating the performance of center-pivot irrigation system operating on variable topography. The model was able to predict flow rate at the pivot, average depth of application, and the uniformity of application for different speeds of rotation, pivot pressure and topography. Center-pivot irrigation system is, however, energy intensive (Batty et al; 1975). The increasing unit cost of energy and possible shortages of energy in the future called for efforts to develop acceptable design concepts and management strategies for reducing energy use which do not excessively lower the uniformity and/or efficiency of application.

The selection of individual sprinklers begins after the water application rate and lateral diameter have been chosen. Many sprinkler manufacturers routinely use computer programs to select sprinklers for center pivots since the discharge requirement and suitability of pressure at each sprinkler outlet is unique and because of the large number of sprinklers along center pivot laterals (James, 1988). The process of selecting sprinkler heads and pipe diameter, involving the calculation of sprinkler flow rate, pressure at the nozzle, system flow rate and pipe friction loss is well suited to a computer program.

In this study, an attempt was made to develop a computer algorithm of a center pivot irrigation system that would perform the design calculations for the sprinkler system given several basic input parameters supplied by the user.

2 DEVELOPMENT OF THE ALGORITHM

2.1 Fundamental Requirements for center-pivot design

The basic inputs that were required to this center - pivot design model include the maximum allowable depletion and the field capacity of the soil on which the irrigation is to be performed, the depth of the root zone and the permanent wilting point of the crop that is planted and the average evapotranspiration for the peak month. The input parameters also include the length of center-pivot lateral, the sprinkler spacing, different pipe sizes available in the market, operating pressure at the last sprinkler, soil intake family and the surface storage ability of the soil.

These variables were combined to form an irrigation system that met the requirements of the crop. In this model, the depth of water to be applied must be decided before starting the design procedure. Equation 1 below is used to compute the application depth, Da in mm.

where MAD is the maximum allowable depletion (decimal), DRZ is the depth of the root zone (cm), FC is the field capacity of the soil (%) and PWP is the permanent wilting point of the crop to be planted (%). The design daily irrigation requirement (DDIR) in mm/day which is the rate at which an irrigation system must supply water to achieve the desired level of irrigation (Annon, 1983) was defined as

$$DDIR = \frac{0.034 \times ET_m^{1.09}}{D_a^{0.09}} \qquad 2$$

where Et_m is the average total evapotranspiration for the peak month (mm). The period of irrigation, (H) in hours was calculated using Equation 3 with the percent field irrigated P_f of 100%.

$$H = \frac{0.24 \quad P_f \quad D_a}{DDIR} \qquad 3$$

The pressure required to operate a center pivot is computed with Equation 4 and 5 with F = 0.543 as given by Chu and Moe (1972).

$$P_d = P_u - K(h_L \pm dz) \qquad 4$$

where P_d, P_u = pressure at down - and upstream positions respectively, (KPa)

h_L = energy loss in pipe between the up and downstream positions (m).

dz = difference in elevation between the up and downstream position (m).

K = unit constant = 9.81

When the change in elevation between the up - and downstream position is uphill, the sign in front of dz is plus (+). Conversely, the sign is negative (-) when the elevation at the upstream location exceeds elevation at the downstream location. Using equation 5 , the energy loss term (h_L) was estimated.

$$h_L = FH_L + M_L \qquad 5$$

where H_L is the headloss in the center pivot lateral and M_L is the minor headloss in joints, couplings etc. M_L is taken to be 10% of the headloss in the lateral pipe. The total system discharge was calculated using equation 6 below

$$QCP = \frac{694.4 \times TFA \times DDIR}{E_a} \qquad 6$$

where QCP is the total system discharge, (Lit/min), TFA is total field area (ha), Ea is the application efficiency of the system and DDIR is as previously defined. Before the individual sprinkler discharge for each sprinkler could be determined, the field length or circumference covered by each sprinkler (FL) must be determined using Equation 7 below.

$$FL = 2\pi r \qquad 7$$

where r is the distance from the pivot to the individual sprinkler (m). After the field length had been determined, the individual sprinkler discharge QSP in Lit/min was calculated using Equation 8

$$QSP = \frac{1.67 \times D_a \times FL \times S}{H \times E_a} \qquad 8$$

where S is sprinkler spacing on center pivot lateral (m). When the individual sprinkler discharge is known, the sprinkler peak application rate (PAR) in mm/hr for each of the sprinklers is computed as follows:

$$PAR = \frac{60 \times QSP}{FL \times S} \qquad 9$$

2.2 Pipe Friction Loss, Pressure Variation and Energy Horse Power Consideration

Before specific sprinklers and nozzles could be selected, the pressure at each point along the lateral was calculated. Four pipe sizes that were considered in this algorithm include 152.4, 203.2, 254.0 and 304.5mm. The lateral pipe diameter was selected based on the least cost method, considering both the variable and fixed costs. The pipe size selected was also tested to satisfy the minimum pressure variation requirement. In this model, it was assumed that the minimum pressure variation between the upstream and downstream ends of the lateral is 20% of the required operating pressure.

The pressure at the pivot was determined by the total friction loss of the system (taking into consideration the total number of outlets on the lateral and the pressure loss between the pivot and the first sprinkler). The total friction loss was determined by calculating the summation of the loss between sprinklers and adding to loss between the pivot and the first sprinkler. The discharge in the next portion of the pipe equals the discharge in the previous portion of pipe plus QSP_i.

$$CQSP_i = CQSP + QSP_i \qquad 10$$

where $CQSP_i$ is the discharge in the next portion of the pipe used to calculate headloss in that portion of the pipe, CQSP is the cumulative discharge in the previous sprinkler and QSPi is the i^{th} sprinkler discharge. Therefore, the loss in any pipe section, *i* is given by Equation 11.

$$FHL_i = \frac{S \times K \times CQSP_i^{1.852}}{PZ^{4.87}} \qquad 11$$

where

$$K = 591722\ (0.285)^{-1.85} \qquad 12$$

the total friction loss for the lateral is given by

$$\sum_{i=1}^{NS} FHL_i \qquad 13$$

where
NS is the total number of sprinklers on lateral. Using equation 14 the pressure variation along the lateral was calculated.

$$PV = \frac{100\,x\,(PVT - PLS)}{PLS} \qquad 14$$

where
PV is the pressure variation along the lateral (%), PVT is pressure at the pivot (KPa), and PLS is pressure at the last sprinkler (KPa).

When the pressure variation at the pivot was known, the headloss in the delivery pipe was calculated using Darcy Weisbach equation and added to pivot pressure in unit of length, height of the delivery pipe and depth of water below the ground surface to arrive at total dynamic head as given by Equation 15.

$$TDH = PVT + HLDP + TDP + EPW \qquad 15$$

where TDH is total dynamic head (m), PVT is the pivot pressure (m), HLDP is headloss in the delivery pipe (m), TDP is height of the delivery pipe (m) and EPW is depth of water below the ground level (m). The brake power (BP) requirement of the pump is given by Michael, 1992 as shown below

$$BP = \frac{CQSP \times TDH}{K \times EPP \times EMM} \qquad 16$$

where K is a unit constant = 75, EPP is efficiency of pumping plant (%) and EMM is the efficiency of motor (%).

2.3 Development of Peak Application Rate- Maximum Application Depth Equations

Application rate beneath center-pivot lateral increased to a peak and then declines to zero as the lateral approaches and then moves past a particular point in the field. Many times the peak rate of application exceeds the recommended basic infiltration rates especially at the downstream end of the lateral. When the peak application rate does not exceed the basic infiltration rate, there will be no possibility of runoff but when the peak application rate exceeds the basic infiltration rate, runoff will occur especially if the volume applied exceeds the volume of water that can be stored in surface depressions plus that required to cause flow over the ground surface.

Gilley (1984) developed a series of relationships between the depth of water that can be applied per irrigation without runoff for surface storage amount of 0, 2.5, 7.6 and 12.7mm and the peak application rate ranging between 4 and 400mm/hr for four soil types. The four soil types were the 0.1, 0.3, 0.5 and 1.0. Soil conservation service (SCS) intake families. The relationships assume an elliptical relationship between application rate, F and time, t in the form $F = at^b$

Before Gilleys' curves can be effectively used, series of equations relating the maximum application depth with the peak application rate were developed for the use in the algorithm. Ten data points were taken from x and y -axis of the curves (i.e peak application rate and maximum application depth axes). Since Gilley assumed that the relationship was elliptical and follows the elliptical relationship between application rate, F and time, t in the form described above, the data points of maximum application depth were substituted for F and the peak application rate substituted for t. The constants a and b were later solved for and the equations showing the relationship between maximum application depth (mm) and peak application rate (mm/hr) for the four soil intake families and the four allowable surface storage values were then developed. Table 1 shows the values of the constants for different surface storage and soil intake families.

3. METHODOLOGY

In other to present the theory and equations in this paper a FORTRAN 77/90 program was developed. The input parameters to the program were the total length of the lateral, sprinklers spacing on the lateral, maximum allowable depletion and depth of root zone for the crop to be planted, the field capacity and basic infiltration rate of the soil to be irrigated, the price per unit length of pipe sizes available in the market and the area of the field to be irrigated. The computer satisfied the ASAE (1985) minimum pressure variation requirements. The operating pressure at each sprinkler, the individual sprinkler discharge and the headloss for the total lateral were calculated. The peak application rate is determined based on the development by Dillion et al, (1972) while the maximum application depth and peak application rate relationship was developed based on the work of Gilley (1984).

3.1 Validation of the computer algorithm

Student t-analysis method was used to test the significance of the disparities between the two sets of output, i.e., between the results of Gilley's development and the result of the computer program. The maximum application depth from the algorithm result and from Gilley's development is shown in Table 2 when the same input information a were used. The two sets of outputs were then compared to see whether there is any statistical difference between them. T-test pair wise comparison shows that the mean of the difference between the two approaches is 0.84mm (when the input information include the peak application rate as computed using Equation 9 and the output, i.e., result is the maximum application depth). The standard error of the difference is 0.744mm. The probability that the difference between the

two sets of results is zero is greater than 26.99%. This shows that there is no statistical difference between the results obtained from these two approaches.

For the purpose of verifying the above deduction, Analysis of variance (SAS, 1987) method was also used to compare the results of the approaches. On the average, maximum application depth from Gilley's curves was found to be 32.96mm while average maximum application depth from the computer algorithm was 32.12mm when the same input information were used. There was no significant difference between what was obtained from Gilley's development and what was obtained from the computer at 1% probability level.

Table 1: Constants for the developed Equations

Surface Storage	Constant in $D_M = a(PAR)^b$	Soil Intake Family			
		0.1	0.3	0.5	1.0
0	a	151.49	99.8109	61.0202	79.3392
	b	-1.015	-0.65689	-0.339764	-0.325274
2.5	a	2589.45	765.629	360.71	342.15
	b	-1.48951	-0.991686	-0.664977	-0.568352
7.6	a	13538.5	2496.94	1770.38	869.015
	b	-1.7456	-1.17328	-0.974059	-0.728766
12.7	a	138525	93199	9399.77	7860.48
	b	-1.99226	-1.80752	-1.18427	-1.07946

4.0 DISCUSSION AND EXAMPLE

The program was tested using four levels each of lateral pipe diameter and sprinkler spacing on the lateral. The levels of pipe diameter are, 152.4mm, 203.2mm, 254.0mm and 304.5mm. These pipe sizes are the common pipe diameters (James, 1988). The levels of spacing of sprinklers on the laterals are; 9.1m, 12.2m, 15.2m and 18.3m. These levels were chosen because the pipe lengths that are commonly available are 9.1m, 12.2m, 15.2m and18.3m (James, 1988). The flow chart for the algorithm is shown in Fig 1. When the sprinkler spacings along the center pivot lateral is singly considered i.e., keeping the lateral diameter constant, the pressure variation along the center pivot lateral was not significantly affected but pressure variation along the lateral increased as sprinkler spacing on the lateral increases. However, the lateral pipe diameter significantly affects the pressure variation along the center pivot lateral. The pressure variation along the lateral decreased with increase in the pipe diameter. This is because as the pipe diameter increases, friction headloss decreases (James, 1988; Addink et al, 1976) thereby causing the pressure variation along the lateral to reduce.

Lateral pipe diameter on the other hand does not affect the discharge of the sprinkler. It can be seen from Fig 2 that on the average, the discharge of the individual sprinkler increases as the sprinkler spacing along the Lateral pipe diameter on the other hand does not affect the discharge of the sprinkler. It can be seen from Fig 2 that on the average, the discharge of the individual sprinkler increases as the sprinkler spacing along the lateral increases. As the distance of the sprinkler from the pivot increases, the discharge requirement of the sprinkler also increases. For all the sprinkler spacing considered, the discharge of the last sprinkler increases from 32.86Lit/min for 9.1m sprinkler spacing to 66.08 Lit/min for spacing of 18.3m. Thus, as the spacing of sprinkler along the lateral increases, large capacity sprinklers will be required. The lateral pipe diameter does not significantly affect the discharge of the individual sprinkler. The spacing of sprinklers along the lateral of center pivot significantly affect the discharge of the sprinkler at 0.1% probability level.

Table 2: Maximum application depth from Gilley (1984) and computer output

Peak application rate(mm/hr)	*Soil intake family*	*Surface storage*	*Maximum application depth(mm)*	
Input information			*Gilley(1984)*	*Computer program*
10	0.1	0	15.0	14.5017
40	0.1	0	3.5	3.5753
10	0.1	2.5	22.0	29.9940
20	0.1	2.5	14.0	13.9492
60	0.1	2.5	7.0	6.7785
20	0.3	2.5	40.0	39.2469
80	0.3	2.5	10.0	9.9254
20	0.3	7.6	54.0	49.2043
80	0.3	7.6	20.0	19.5725
100	0.3	7.6	18.0	16.8735
30	0.5	0	32.0	35.7360
50	0.5	0	15.0	14.6504
70	0.5	0	7.8	8.1427
40	0.5	12.7	65.0	59.0882
100	0.5	12.7	28.0	30.3036
50	1.0	12.7	125.0	115.2070
80	1.0	12.7	65.0	69.3649
200	1.0	12.7	30.0	25.7976
60	1.0	7.6	68.0	70.6726
200	1.0	7.6	20.0	17.7042

The pressure at each nozzle on the average when the sprinkler spacing along the lateral is held constant decreases with increase in the lateral pipe diameter. Figure 3 shows the relationship between the discharge pressure and the sprinkler position from the pivot. Number 0 corresponds to the pivot point while number 5 corresponds to the fifth sprinkler from the pivot point. The distance of the sprinklers is therefore the sprinkler number multiply by spacing of sprinkler on the lateral (the program assumes uniform spacing on the lateral). From Fig 3, the discharge pressure of the nozzle increases as the distance from the pivot increases. The pressure variation between the two ends of the lateral pipe increases as the pipe diameter decreases. The center pivot lateral diameter significantly affect the pressure at the nozzle of the individual sprinkler at 0.5% probability level. As the pipe diameter increased from 50.8mm to 152.4mm the average pressure at the nozzle of the individual sprinkler reduces from 365.77Pa to 350.04KPa. However, the spacing of sprinklers on the center pivot lateral did not significantly affect the pressure at the nozzle.

CONCLUSION

A computer algorithm for the design of a center pivot sprinkler irrigation system was developed. When the results of the developed program were compared with the results of a past design, it was found that the program accurately predict the maximum application depth based on peak application rate, surface storage of soil and SCS soil intake family when compared to the results from Gilley's development in 1984. With this computer program there will be no need to read curves to insert values of depth of water to be applied in other to obtain peat application rate.

When some of the input data were changed to see the effect on the design output, the results revealed that the sprinkler spacings along the center pivot lateral does not significantly affect both the pressure variation along the lateral and the pressure at the nozzle of the individual sprinkler. Sprinkler spacings significantly affect the individual sprinkler discharge. However, the lateral diameter affects both

the pressure variation along the lateral and the individual sprinkler nozzle pressure but does not affect the individual sprinkler discharge.

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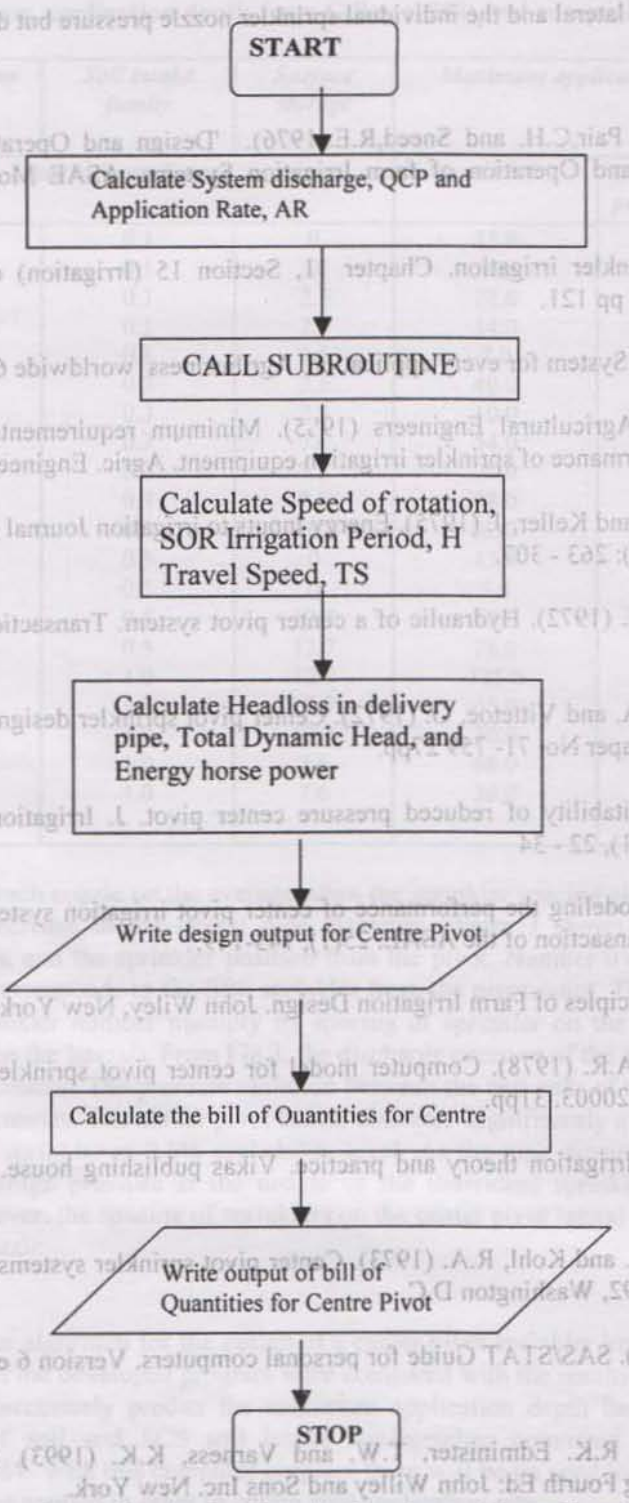


Fig. 1 : Centre Pivot Design Flowchart

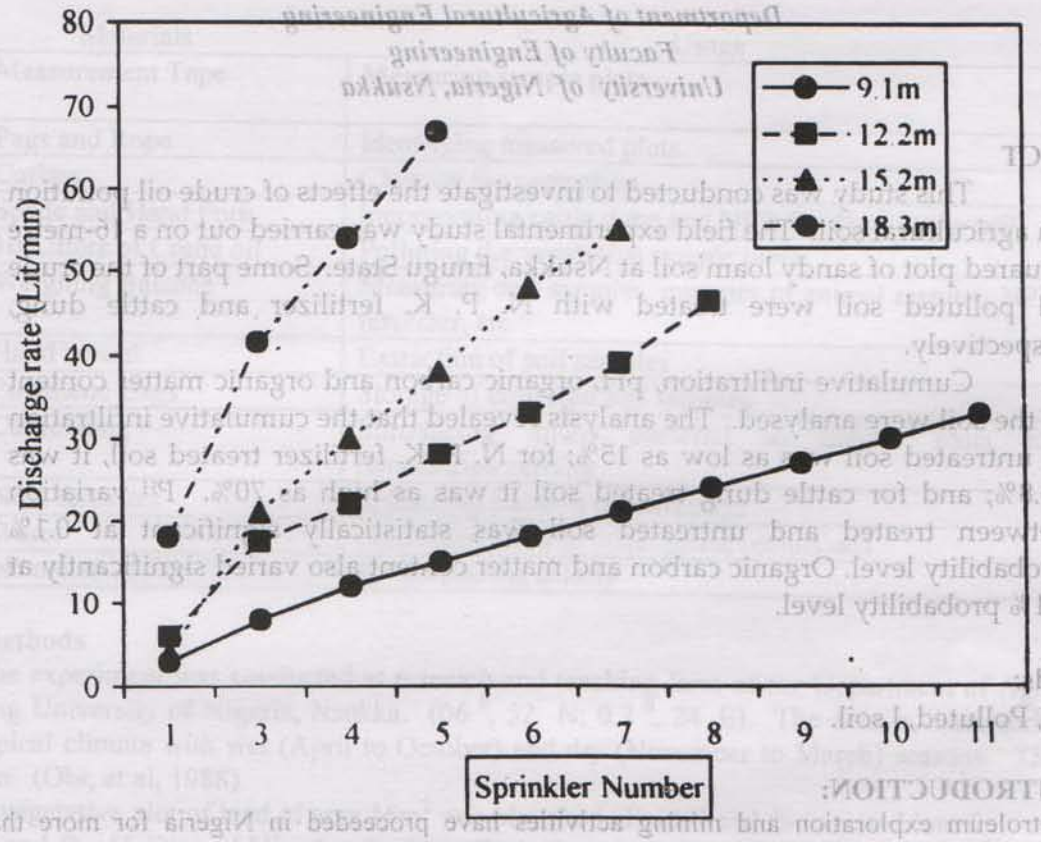


Fig. 2: Spacing effects on individual sprinkler discharge

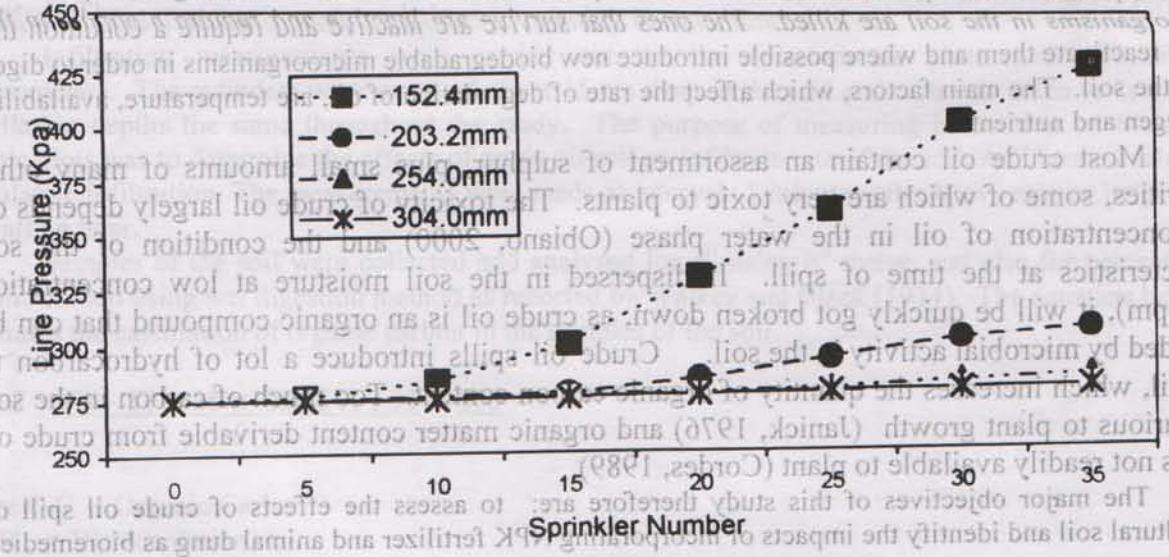


Fig. 3: Sprinkler discharge and Line Pressure of individual nozzle at spacing of 12.2m

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BIOCHEMICAL REMEDIATION OF CRUDE OIL POLLUTED SOIL FOR CROP PRODUCTION

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ABSTRACT

This study was conducted to investigate the effects of crude oil pollution on agricultural soil. The field experimental study was carried out on a 16-metre squared plot of sandy loam soil at Nsukka, Enugu State. Some part of the crude oil polluted soil were treated with N. P. K. fertilizer and cattle dung, respectively.

Cumulative infiltration, pH, organic carbon and organic matter content of the soil were analysed. The analysis revealed that the cumulative infiltration in untreated soil was as low as 15%; for N. P. K. fertilizer treated soil, it was 66.8%; and for cattle dung treated soil it was as high as 70%. PH variation between treated and untreated soil was statistically significant at 0.1% probability level. Organic carbon and matter content also varied significantly at 0.1% probability level.

Key words:
Crude oil, Polluted, l soil.

1.0 INTRODUCTION:

Petroleum exploration and mining activities have proceeded in Nigeria for more than three decades. Inevitably, some oil spillages have occurred at some places, which resulted, to pollution or degradation of agricultural soils. Crude oil characteristics have very important bearing on the impact it may have when spilled into the environment. The first impact on the soil was to destroy the thin layer of fertile topsoils, which provides nutrient to the plants (Cordes, 1989). During oil spill, most microorganisms in the soil are killed. The ones that survive are inactive and require a condition that would reactivate them and where possible introduce new biodegradable microorganisms in order to digest oil in the soil. The main factors, which affect the rate of degradation of oil, are temperature, availability of oxygen and nutrients.

Most crude oil contain an assortment of sulphur, plus small amounts of many other impurities, some of which are very toxic to plants. The toxicity of crude oil largely depends on the concentration of oil in the water phase (Obiano, 2000) and the condition of the soil characteristics at the time of spill. If dispersed in the soil moisture at low concentration (<18ppm), it will be quickly got broken down, as crude oil is an organic compound that can be degraded by microbial activity in the soil. Crude oil spills introduce a lot of hydrocarbon to the soil, which increases the quantity of organic carbon content. Too much of carbon in the soil is injurious to plant growth (Janick, 1976) and organic matter content derivable from crude oil spill is not readily available to plant (Cordes, 1989).

The major objectives of this study therefore are: to assess the effects of crude oil spill on agricultural soil and identify the impacts of incorporating NPK fertilizer and animal dung as bioremedies

2.0 MATERIALS AND METHODS

2.1 The materials used during the experimental study are as shown in table 1.

Table 1: Materials used during the experiment.

	Materials	Usage
A	Measurement Tape	Measuring sample plots
B	Pegs and Rope	Identifying measured plots.
C	Cutlass	Clearing the vegetation
D	Spade and Hand Fork	Incorporating cattle dung and NPK fertilizer in the soil
E	10 Litters of Crude oil	Polluting the vegetative sample plots.
F	Weighing Balance	Measuring soil samples, quantity of animal manure, NPK fertilizer, etc
G	Hand trowel	Extraction of soil samples
H	Polythene Bags	Storage of collected soil samples
I	Cattle dung	Introducing micro bacterial to sample plots for remediation activity
J	NPK fertilizer	Enhancing bacteria culturization
K	Water	Promotion of oil in water phase (emulsion)
L	pH meter	For measuring acidity

2.2 Methods

The experiment was conducted at research and teaching farm of the Department of Agricultural Engineering University of Nigeria, Nsukka. (06 °, 52' N; 0.7 °, 24' E). The area is characterized by a humid tropical climate with wet (April to October) and dry (November to March) seasons. The soil is sandy loam. (Obi, et al, 1988)

A vegetative plot of land of area $16m^2$ was ploughed, divided and demarcated into four sub-plots: A, B, C and D. 45 litres of Nigerian fresh medium viscous crude oil (specific gravity approximately 0.87) was obtained from Isimiri flow station owned by Shell Petroleum Development Company (SPDC). The crude oil was poured evenly on the prepared subplots, B. C and D only in March, 2001. In April, 2001, subplots C and D were treated with 3kg and 5kg of cattle dung, respectively; leaving subplot B untreated. These treatments were carried out bi-monthly for ten months.

Infiltration measurements were carried out on the four sample plots with cylindrical infiltrometers. The cylinders were installed about 15 cm deep in the soil and care was taken to keep the installation depths the same throughout the study. The purpose of measuring infiltration on the four sample plots was to determine the effects of crude oil soil on infiltrate rate of the soil. And hence evaluate cumulative infiltration. The measurements were made at intervals 5 minutes after heavy rain or irrigation for half an hour.

Samples of the soil were collected and analysed for p^H using p^H meter; and also for percentage organic carbon using wet digestion method as reported by Walkey and Black (1934). The equation below illustrates the calculation of organic carbon in the samples of the soil.

$$\% \text{ O.C} = \frac{(B - T) \times M \times 0.003 \times 1.33}{6} \times \frac{100}{1}$$

where O.C = Organic Carbon
B = Blank solution, ml
T = Titre – volume of sample. Cm^3
M = Molarity of ferrous suphated used mg/lkg

0.03 = Atomic weight of carbon, kg
1.33 = Recovery factor

Organic mater content was determined like organic carbon by using the same wet digestion method. The equation for calculating organic matter according to Walkey and Black (1934)

$$\% \text{ O.M} = \% \text{ O.C} \times 1.724$$

where, O.M = Organic Matter
O.C = organic carbon
1.724 = Constant (Van Bemmelen factor)

3.0 RESULTS AND DISCUSSION

The mean values of cumulative infiltration (Tables 2 to 5), were plotted on graph to depict the influence of crude oil on the rate of water infiltration as shown in figures 1. Cumulative infiltration is significantly low in polluted and untreated soil. In contrast, cumulative infiltration was reasonable high in NPK treated soil and it highest in cattle dung treated soil

Tables 6 and 7 show the average values of p^H variation in response to treatments. For the polluted and untreated soil, the average p^H value was 4.20 which if compared with the average p^H values for the unpolluted, 6.90, has a difference of 2.50. For the NPK and cattle dung treated soils, the average P^H values were 6.35 and 6.79, respectively, which shows that the difference is less pronounced in cattle dung treated soil. Tables 8 and 9 present the average percentage organic carbon and organic matter for unpolluted, polluted and polluted and treated soils. The values of organic carbon and organic matter for polluted and untreated soil were significantly high.

The high organic matter content in the polluted and untreated soil does not necessarily mean that the soil is fertile. It indicates that the oil molecules locked the minerals in the organic matter.

Table 2 Results of the Infiltration Measurements on unpolluted (control)

Time t (min)	Water level X_i (cm)	Ref Pt X_o (cm)	Depth D (cm)	D/t (cm/min)	Average infiltration rate (cm/hr)	Average Cumulative infiltration (cm)
5	8.5	15.0	6.5	1.3	78	6.5
10	7.1	15.0	7.9	0.8	48	14.4
15	6.0	15.0	9.0	0.6	36	23.4
20	5.7	15.0	9.3	0.5	30	32.7
25	5.5	15.0	9.5	0.4	24	42.2
30	5.2	15.0	9.8	0.3	18	52.0

Table 3 Result of the Infiltration Measurement of Crude Oil Polluted Soil

Time, t (min)	Water level, X_t (cm)	Ref. Pt X_o (cm)	Depth D o (cm)	D/t cm/Min)	Average infiltration rate (cm/ hr)	Average Cumulative Infiltration (cm)
5	14.5	15.0	0.5	0.1	6.0	0.5
10	13.7	15.0	1.3	0.13	7.8	1.8
15	13.5	15.0	1.5	0.10	6.0	3.3
20	12.6	15.0	2.4	0.12	7.2	5.7
25	12.6	15.0	2.4	0.096	5.76	8.1
30	13.2	15.0	1.8	0.06	3.6	9.9

Table 4 Result of the Infiltration Measurements of rude Oil Polluted Soil treated with NPK Fertilizer

Time, t (min)	Water level, X_1 (cm)	Ref Pt X_0 (cm)	Depth D (cm)	D/t (cm/min)	Average infiltration rate (cm/hr)	Average Cumulative infiltration (cm)
5	10.8	15.0	4.2	0.84	50.4	4.2
10	10.2	15.0	4.8	0.48	28.8	9.0
15	9.5	15.0	5.5	0.36	21.6	14.5
20	8.8	15.0	6.2	0.31	18.6	20.7
25	8.1	15.0	6.9	0.28	16.8	27.6
30	8.1	15.0	6.9	0.23	13.8	34.5

Table 5 Result of The Infiltration Measurements of C rude Oil Polluted Soil treated with Cattle Dung

Time, t (min)	Water level X_1 (cm)	Ref. Pt X_o (cm)	Depth, D (cm)	D/t (cm/min)	Average infiltration rate (cm/hr)	Average Cumulative infiltration (cm)
5	10.6	15.0	4.4	0.88	52.8	4.4
10	10.1	15.0	4.9	0.49	29.4	9.3
15	9.4	15.0	5.6	0.37	22.2	14.9
20	8.9	15.0	6.1	0.31	18.3	21.0
25	7.8	15.0	7.2	0.29	17.3	28.2
30	7.4	15.0	7.6	0.25	15.2	35.8

Table 6: pH values in H_2O

Sub plot	pH before pollution	P^H Variation in response to treatment				
Unpolluted (control)	7.10	7.10	7.10	7.10	7.10	7.10
Polluted	7.10	6.05	5.060	5.20	4.75	4.30
Polluted + NPK	7.10	6.05	5.10	5.00	5.50	6.40
Polluted + cattle dung	7.10	6.05	5.40	5.40	5.80	6.80

Table 7 pH value in KCL

Subplot	PH before Pollution	PH Variation in response to treatment				
Unpolluted (control)	6.90	6.90	6.90	6.90	6.90	6.90
Polluted	6.90	5.95	5.45	4.95	4.60	4.20
Polluted + NPK	6.90	5.95	5.05	4.80	5.30	6.35
Polluted + cattle dung	6.90	5.95	5.03	5.40	5.65	6.79

Table 8: Percentage Organic carbon of unpolluted, polluted and treated soils

unpolluted (control)	0.77	0.78	0.78	0.77	0.77	0.77
Polluted	3.48	3.46	3.41	3.41	3.40	3.37
Polluted + NPK	3.48	3.30	2.03	1.11	0.88	0.80
Polluted + cattle dung	3.48	3.64	2.32	1.39	1.02	0.91

Table 9. Percentage Organic Matter of unpolluted, polluted and treated soils

Unpolluted (control)	1.33	1.34	1.34	1.33	1.33	1.33
Polluted	5.99	5.97	5.91	5.88	5.86	5.86
Polluted + NPK	5.99	5.69	3.49	1.91	1.52	1.38
Polluted + cattle dung	5.99	6.28	3.99	2.39	1.76	1.57

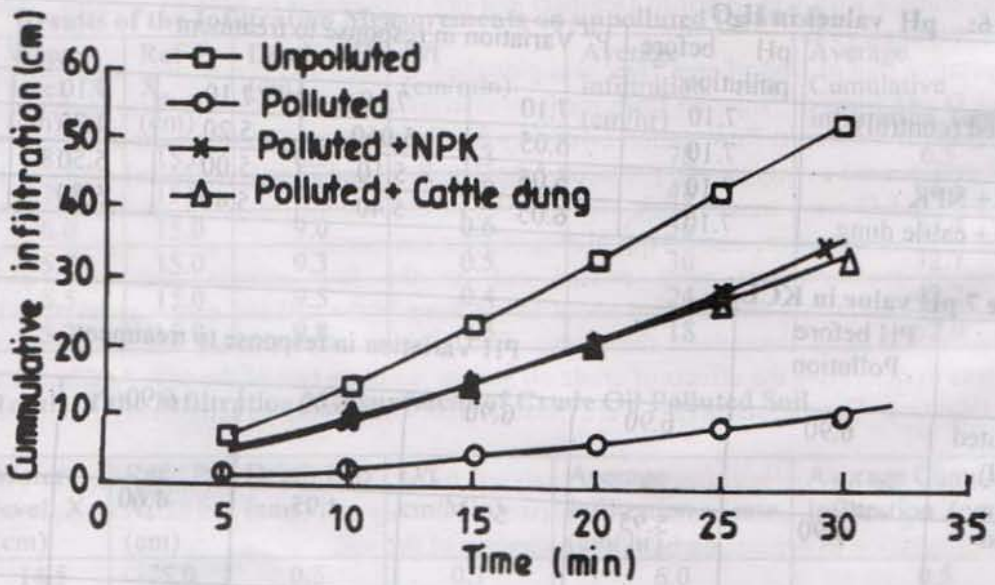


Figure 1: Graphs of cummulative infiltration against time for unpolluted, polluted, polluted + NPK and polluted + cattle dung

CONCLUSION

Cumulative infiltration and pH measured in this study shows that NPK and cattle dung can be used for biochemical remediation. Cattle dung incorporation in oil polluted soil has more realistic effects in correcting the distorted soil components due to oil pollution. Crude oil pollution introduce more carbon in to the soils, lock-up the available nutrients, which was indicated in high organic matter content of polluted and untreated soil.

Biochemical remediation of crude oil polluted soil is an effective means of land reclamation for agricultural purposes. Oil industries in Nigeria should apply biochemical remediation to oil polluted soils as against other methods.

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RANKING POTENTIAL EVAPOTRANSPIRATION MODELS IN THE PREDICTION OF MAIZE WATER REQUIREMENT IN PORTHARCOURT AREA, NIGERIA.

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ABSTRACT

Water requirement or evapotranspiration of crop, ETc, is usually calculated as the product of the potential evapotranspiration (PET) and the crop coefficient (Kc). PET could easily be obtained indirectly using empirical models through climatic observations. But many of these models, including the Penman (1948), Blaney Criddle (1950), Hargreaves(1956), Jensen-Haise (1963), Thornthwaite(1968), and Blaney-Morin-Nigeria (BMN) (1983) have been observed not to be sufficiently sensitive in hot tropical climates as compared to temperate regions of the world where they may have been formulated. This article attempts to verify the reliability of these models in estimating PET in Port Harcourt area and to further compare the closeness of the estimates to maize ET values got from lysimeter experiments. The results showed that daily estimates of PET in the months of each year is highest with Jensen-Haise (8.85mm/day) model and lowest with Penman's (3.07mm/day) model. That, apart from Penman and BMN, non of the other models including class A pan could adequately predict maize water requirement in PortHarcourt area, Nigeria.

KEYWORDS:
Ranking, Potential Evapotranspiration, Model, Maize, water requirement, Port Harcourt

1.0 INTRODUCTION

The role of water in promoting crop yield, amidst several other cultural practices, has long been an important issue amongst scientist. Many of these workers have contributed in diverse ways to the formulation of successful irrigation management strategies. These strategies include the development of evapotranspiration (ET) models which predict response of crop yield to water for particular crops, locations, and even cultural practices.

Actually, prediction of ET is usually carried out through direct measurements (i.e. lysimeters, field plots, water balance, soil moisture depletion studies and evaporations pans) or indirectly by using empirical formulae obtained through climatological observations (i.e. Penman, Jensen-Haise, Blaney Criddle, Hargreaves, Thornthwaite, Blaney-Morin-Nigeria , etc). Direct measurements, where measuring instruments are available, naturally give best evaluation of ET; while indirect measurements give a more rapid, but not necessarily accurate results (Jensen and Haise, 1963; Michael, 1978; Hansen et al; 1979 and Salih and Sendil, 1984). The formulas used in the indirect method, range from simple equations, expressing ET as a function of temperature alone, to complex models requiring extensive data and long hours of calculation. The formula developed by Thornthwaite (1948) is an example of the former group of formulas usually referred to as temperature-based models. The Penman (1948) formula is an example of the complex models.

It has been observed, however, that many of these empirical models, though simple, are not sufficiently sensitive in areas where the temperature is relatively constant while other meteorological factors that also promote evapotranspiration vary (Michael, 1978; Hashemi and Haliban, 1979). It is therefore important to verify or even recalibrate these models when used within a new geographical region or climatic area like PortHarcourt, Nigeria, to account for relational changes between meteorological factors such as net radiation, air temperature, elevation, advection and relative humidity.

Studies relating crop yield , particularly maize, to water use during the dry-season in PortHarcourt area, Nigeria, has been made (Ayotamuno et al, 2000). Values of mean daily water consumption or evapotranspiration of maize using lysimeter under non limiting water conditions have been compared with daily average values of potential evaprtranspiration (PET) obtained from long term (1983-1994)

pan evaporation records observed in the study area (Ayotamuno et al, 1997). The present article compares corn ET values, from lysimeter measurements, with values obtained from six evapotranspiration models and class A pan values, using climatic records. The aim is to ascertain the reliability of both the Nigerian and foreign models in estimating PET in Port Harcourt and to check the closeness of these estimates to actual maize ET values obtained with lysimeter. The model with the closest PET value relative to that of lysimeter ET, will then be ranked as the first and then followed by others. Therefore the objective of this article is:

a) to obtain PET values of 7 models, including class A pan, using climatic data in Port Harcourt area.
b) To compare these PET values from each model with maize ET values obtained from lysimeters and ranking each according to their closeness to the later measurements.

1.1 Description of Models

The PET models considered for verification and classification in this article are; Penman (1948), Blaney Criddle (1950), Hargreaves(1956), Jensen-Haise (1963), Thornthwaite(1968), and Blaney-Morin-Nigeria (BMN) (1983).

Penman (1948) made the most complete analysis using several climatic variables. He proposed an equation for evaporation from open water surface, based on a combination of energy balance and sink strength which is as follows:

$$E_0 = \frac{\Delta Qn + YEa}{\Delta + Y} \qquad 1$$

in which,

E_o = evaporation from open water surface, (an average factor 0.7 converts E_o to PET) mm/day
Δ = slope of saturation vapour pressure versus temperature curve (de_a/dT) at the mean air temperature Ta, in mmHg per °C
e_a = saturation vapour pressure of the evaporating surface (°s) in mmHg at mean air temperature Ta
Ta = mean air temperature in °K
Qn = net radiation (mm of water)
= $Q_A(1\text{-}r)(0.18 + 0.55n/N) - \sigma Ta^4(0.55 - 0.092e_d)(0.10 + 0.90n/N)$
Q_A = Angot's value of mean monthly extra-terrestrial radiation, mm of water/day
n/N = ratio between actual and possible hours of bright sunshine
σ = Stefan-Boltzman constant
e_d = saturation vapour pressure of the atmosphere, in mmHg at dew point
Y = psychrometric constant
Ea = an aerodynamic component in which, e_s is considered equal to e_a
Ea = $0.35(e_a - e_d)(1+0.0098U_2)$
U_2 = wind speed in miles/day at 2 metres height

The principal limitation of the Penman approach is the lack of sufficient weather measurements in most localities. Only a few climatological stations record the needed data. Hence the formula, even though quite reliable does have some practical limitations.

Blaney and Criddle (1950) observed that the amount of water consumptively used by crops during their growing seasons was closely correlated with mean monthly temperatures and day light hours. The relationship is stated as follows:

$$PET = 25.4K\,F = 25.4K\sum\frac{tP}{100} \qquad 2$$

Where,

PET = consumptive use of crop in mm for a given time period.
K = empirical crop consumptive use coefficient

F = sum of the consumptive use factors for the period
t = mean temperature in °F
P = percentage of day-time hours of the year; occuring during the period.

Its limitation is that it cannot estimate consumptive use for shorter time periods than one month due to the use of temperature as the only climatic variable.

Thornthwaite (1968) assumed that an exponential relationship existed between mean monthly temperature and mean monthly consumptive use. The formula is as follows:

$$PET = 1.6(10t/I)a \quad 3$$

in which

PET = adjusted potential evapotranspiration, cm per month (month of 30 days each and 12 hours day time)
t = mean monthly temperature, °C
I = annual or seasonal heat index, the sum of 12 values of monthly heat indices (i) when, $i=(t/5)1.514$
a = an empirical exponent computed by the equation
$= 0.000000675I^3 - 0.0000771I^2 + 0.01792I + 0.49239$

The Thornthwaite formula gives a reasonable estimate of PET in the temperate, continental climate of North America where the formula was originally derived because there the temperature and radiation are strongly correlated.

Jensen and Haise (1963) used observations of consumptive use from the Western United States to develop a linear relationship for estimating PET as ;

$$PET = (0.025Tm + 0.078)\, R_s/58.5 \quad 4$$

Where,

PET = Jensen-Haise evapotranspiration (mm)
Tm = The mean of daily minimum and maximum air temperature °C
Rs = daily solar radiation cal/cm^2

Hargreaves (1956) based his work on data from grass lysimeters. The formula has been extensively used in Latin America to estimate crop water requirements. In equation form,

$$PET = 0.0135(T + 17.78)R_s \quad 5$$

Where,

PET = crop potential consumptive use in langleys/day
T = average daily temperature in °C
R_s = incident solar radiation in langleys/day

Duru (1983) obtained his equation through the modification of the Blaney and Morin (1942) equation which puts much emphasis on humidity (a variable parameter in Nigeria) apart from the temperature, to obtain the Blaney-Morin-Nigeria (BMN) model. The equation is as follows:

$$PET = r_f(0.45t + 8)(520 - R^{1.31})/100 \quad 6$$

Where,

PET = potential evapotranspiration in mm
r_f = ratio of maximum possible radiation to annual maximum
t = temperature in °C
R = relative humidity in %

2.0 METHODOLOGY

This article is a continuation of the research relating maize yield to water use at the research farm of the Rivers State University of Science and Technology, PortHarcourt, Nigeria. PortHarcourt consists of a very humid climate with an average daily rainfall of about 210mm, out of which about 70% falls between May and August, and the rest of the year, especially from late November to March, is generally dry and sunny. Long term, (1983-1994) mean monthly air temperature and solar radiation ranges between 25°C–28.5°C and 525cal/cm^2/day-780ca/cm^2/day, respectively (Ayotamuno et al, 1997). For the purpose of computing PET in the selected models for this article, more climatic data was collated from records observed at the university meteorological stations. These include relative humidity , daylight hours, wind speed, vapour pressure and sunshine hours. Mean monthly values of each of the parameters in last 12 years, were inserted in each of the models to calculate the PET.

Pan evaporation measurements were obtained using a standard United States Weather Bureau class A pan evaporimeter. The design of the evaporimeter and collection of daily evaporation readings had been described in Ayotamuno et al (1997). A factor of 0.7, the pan coefficient, was then applied to all the readings to convert the observed evaporation to potential evapotranspiration.

Actual evapotranspiration of maize, ET, was obtained with a non-weighing water table lysimeter under non limiting water table conditions. The dimensions of the lysimeter, water supply, drainage and maize planting arrangements had been discussed (Ayotamuno et al, 1997; Ayotamuno et al., 2000). Planting of maize was done twice in the year, that is January/February to April/May and (b) September to December. Crop dry matter and marketable yield were determined by hand harvesting from the lysimeters, oven drying to a constant weight , adjusted to 12.5% grain moisture on dry weight basis. The lysimeter experiment lasted 2 years.

Using the aforementioned model equations, monthly values of potential evapotranspiration (PET) were computed from the corresponding climatic records. Data from class A pan was also computed to similar presentations. These monthly PET readings were later converted to daily PET readings by dividing with the respective number of days in the months. The various PET readings and the class A pan values were compared amongst themselves and with the lysimeter ET values obtained during the four planting seasons of the experiment.

Linear regression analysis was then used to test agreement and variation of model estimates with lysimeter measurements made during periods of full lysimeter plant cover over the 2 year period of the research. According to Allen and Pruitt (1986) days during which the lysimeter crops were at less than full cover (that is between planting and about 40 cm height), should be deleted from the analysis. With ET as lysimeter-measured evapotranspiration; and PET as the particular evapotranspiration model estimate, the regression model used was of the form:

$$ET = a + b\,PET \qquad 7$$

in which (a) and (b) are constants representing the intercept and slope of the regression line. The value of (a) = 0.0 and that of (b) = 1.0 indicating perfect agreement between predicted and observed values. The correlation coefficient, denoted by r, gives the reliability to be expected of the predictor. A perfect prediction would be indicated by r=1.0. Also the closeness of ratios of central tendency (like the average and the median ratios) to unity was also considered in the line with procedures of evaluation by Hargreaves and Samani (1982). The result of these comparisons was used to rank each of these models according to their suitability to predict maize evapotranspiration in Port Harcourt area.

3.0 RESULTS AND DISCUSSION

Climatic data

Long term (1983-1994) mean climatic data recorded in the study area is given in Table 1. Generally the data show relatively high temperatures and solar radiation from the month of November through April and little rainfall during this period. Rainy season actually begins from about May and end in October. During this period parameters like temperature, solar radiation, pan evaporation and sunshine

hours are low. From Table 1, the month of February recorded the highest temperature, 28.4°C and solar radiation, 778.7ca/cm^2; while the highest rainfall, 352.5mm, occurred in the month of September.

Comparison of estimates of PET by different methods

Given in Table 2 are the estimates of the long term (1983-1994) average daily PET readings in each of the months using the various models including the PET values of the class A pan. From the table, daily estimates of PET, in each of the months of the year is highest with Jensen-Haise and lowest with the Penman method. For instance daily PET values computed with Jensen-Haise method ranged between 10.46mm/day in the dry season month of February and 6.5mm/day in the rainy season month of July, with an annual average of 8.85mm/day. PET values from the Penman method, on the other hand, ranged between 3.67mm/day in December to 2.36mm/day in August with an annual average of 3.07mm/day.

Comparison of PET estimates from models with actual maize ET

Table 3a to 3d, respectively, shows a comparison of the estimates of PET during the months of the four planting seasons of the experiment and the actual ET obtained from lysimeter measurements. The cumulative values are given in Figure 1. The tables and the figure show that the evapotranspiration values could be divided into 3 categories. The first category, the Jensen-Haise, Hargreaves, Blaney Criddle and Thornthwaite estimates are distinctly higher than those of the remaining methods; while the second category, lysimeter, Penman and the Blaney- Morin- Nigeria (B.M.N.) reflects relatively comparable values. The pan estimates are in between these two estimates. The Tables 3a to 3d further shows that the class A pan values are closer to the values of the second category during the first planting season (January – May) and closer to the first category during the second planting season (September–December) of this research. These pan values are respectively 30 - 35%, 32 - 33% and 29 - 31% higher than estimates obtained by the Lysimeter, Penman and B.M.N methods.

In Figure 1, the measured maize ET, started at a slow rate, but after 30 or 40 days, as the maize grew and began to cover the bare soil, the rate of measured ET (indicated by the upward slope of the ET curve) approached the rate of PET, calculated from the models. As the plant matured and began to dry out, the measured evapotranspiration rate in some cases once again tended to drop below the potential rate. In other words the rate of transpiration, (depending upon the vegetative cover) and not only evaporation, had a major influence on the outcome of the maize ET value. That is, a little increament in the maize vegetative cover results in the ET tending towards the PET values.

Ranking of the PET models in relation to closeness to lysimeter ET values

A statistical analysis of the computed PET values in Table 2 was done, using the Duncan Multiple Range Test. The results of these computations and correlations are given in Table 4. The table shows that the potential ET value for Penman, 3.23 mm/day is the least followed by that of the Blaney-Morin- Nigeria, 3.45 mm/day and Class A pan, 4.17 mm/day. The Jensen - Haise method had the highest potential ET value of 9.35 mm/day. There were no correlations between the different methods except the Penman and the Blaney- Morin- Nigeria (B.M.N.). The means of the Penman and B.M.N. methods were found not to differ at 5% significant level using Duncan's Multiple range test. This good correlation may be expected since the two methods employ relatively similar climatic parameters. For instance, it only the Penman and the BMN models that used the relative humidity values in Table1 in their PET computations. The rest of the models had no relative humidity term, having been modeled for temperate based countries of Europe and North America. These models may not be suitable for Port Harcourt area, which has one of the highest relative humidity values in Nigeria. The probable solution for their use in this part of the world may be that they be recalibrated. Table 4 also shows that the numerical PET values of the other models, including the class A pan, varies greatly from the Penman and the B.M.N models.

The preceding results, generally, suggest that from a practical point of view in irrigation planning, the selected models in Table 4 exhibit a great deal of contrast between each other in the same study area except the Penman and BMN methods. The standing question However is, not withstanding this difference, which of these methods should be adopted, under the Port Harcourt climatic conditions, to predict accurate ET for optimum maize yield. To answer this question in a rational manner, these results must be compared with measured actual evapotranspiration values in the study area.

The ET values for optimum yield of maize in this experiment was 302mm or about 3.24 mm/day depth of irrigation water (Ayotamuno, 1997). This optimum maize ET value was used to evaluate and rank the selected models. The criteria used for evaluation were obtained from Jensen's (1974) and Hargreaves and Samani's (1982) procedures of evaluation in addition to the closeness of the average ratio to unity. The result of the rating is shown in Table 5. The result ranked Penman and B.M.N. methods, respectively, in the first and second place, class A Pan method in the third place, Thornthwaite, fourth, Blaney Criddle, fifth and Hargreaves, sixth place. The Jensen-Haise method is rated in the lowest rank.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Six potential evapotranspiration (PET) models viz: Penman, Jensen-Haise, Blaney Criddle, Hargreaves, Thornthwaite, and Blaney-Morin-Nigeria, plus class A plan, were used to predict the water needs of maize during the dryseason in PortHarcourt area, Nigeria. This was carried out by comparing the closeness of their respective computed PET values, obtained from the climatic data, in the study area, to actual maize evapotranspiration, ET, measured with lysimeters under non-limiting water conditions. The result of these comparisons showed that none of the models including the class A pan estimates can adequately predict maize water requirement in the study area, excepting the penman and BMN models. This to a large extent, is because of the lack of a relative humidity term in the other models, whose formulation may not have taken into consideration this important climatic parameter in PortHarcourt area, Nigeria. In spite of the fact that both the Penman and B.M.N. models have comparable accuracy of predicting corn consumptive use in PortHarcourt area, Nigeria, the advantage of BMN is that it is less complex and sophisticated and so could be used to compute ET with easily available meteorological parameters of temperature, radiation and humidity. Based on this research, it is therefore recommended that a correlating equation between the BMN and the ET of maize be obtained and this equation be adopted for use in predicting water requirements for maize yield in PortHarcourt area, Nigeria.

Table 1. Long term mean monthly climatic data at the study area (1983-1994)

Month	Mean temp °C	Solar radiation ca/cm/day	Rainfall mm	Relative Humidity %	Sunshine hours	Wind speed Knots	Vapour pressure mbar	Pan evaporation mm/day
Jan.	27.0	737.4	17.9	77.0	4.1	19	26.5	7.86
Feb.	28.4	778.7	54.6	82.0	4.3	33	27.0	7.06
Mar.	28.3	741.6	107.2	83.0	4.0	37	28.0	5.74
Apr.	28.0	769.7	138.6	85.0	4.8	32	29.8	5.21
May	27.3	730.3	230.9	86.0	4.2	30	30.4	5.26
June	26.5	680.8	271.7	88.0	3.8	30	29.3	4.14
July	25.8	524.7	346.1	89.3	2.6	25	28.7	4.03
Aug.	25.8	537.5	323.2	92.1	2.0	22	28.2	4.70
Sept	26.2	612.3	352.5	90.0	2.6	30	28.5	4.86
Oct	26.4	654.0	217.4	89.0	2.8	28	29.0	5.00
Nov	27.3	720.4	73.4	87.0	3.6	24	29.5	5.90
Dec	26.3	720.5	24.3	81.0	3.8	20	27.0	7.37

Table 2: Mean daily Potential Evapotranspiration at the Study Area(1983-1994)

Estimation method	Evapotranspiration, mm											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Penman	3.60	3.56	3.61	3.41	3.16	2.78	2.51	2.36	2.64	2.63	2.92	3.67
BMN	4.04	4.46	3.90	3.68	3.34	2.89	1.95	2.05	2.43	2.69	3.17	3.55
Thornthwaite	4.73	5.73	5.79	5.55	5.07	4.69	4.06	4.07	4.23	4.37	4.83	4.23
Blaney Criddle	6.86	6.33	6.47	6.47	6.54	6.04	5.78	5.81	5.84	5.97	5.92	6.40
Hargreaves	7.67	7.81	7.96	8.21	7.64	7.00	5.31	5.44	6.25	6.71	7.60	7.36
Jensen Haise	9.57	10.46	9.95	10.3	9.54	8.68	6.51	6.63	7.72	8.30	9.40	9.12
Class A pan	5.50	4.94	4.02	3.65	3.68	2.90	2.82	3.29	3.40	3.50	4.13	5.16

a The Blaney-Morin- Nigeria Method

Table 3a: Estimates of PET and Lysimeter maize ET during the first planting period (2nd February to 5th May 1993)

Estimation method	Evapotranspiration, mm				
	Feb	Mar	Apr	May	Feb-May
ET (Lysimeter)	42.28	114.47	135.59	19.18	311.52
Penman	96.12	111.91	102.30	15.80	326.13
B.M.N.[a]	120.42	120.90	114.40	16.70	372.42
Class A Pan	133.38	124.62	109.50	18.40	385.90
Thornthwaite	154.71	179.49	166.50	25.35	526.05
Blaney Criddle	170.91	200.57	194.10	32.70	598.28
Hargreaves	210.87	246.76	246.30	38.20	742.13
Jensen Haise	282.42	308.45	309.30	47.70	947.87

a The Blaney -Morin -Nigeria method

Table 3b: Estimates of PET and Lysimeter maize ET during the second planting period(25th September to 31st December 1993)

Estimation method	Evapotranspiration, mm				
	Sept	Oct	Nov	Dec	Sept - Dec
ET (Lysimeter)	3.50	72.20	112.70	91.60	278.00
Penman	15.84	81.53	87.60	95.42	280.39
B.M.N.[a]	14.58	83.40	95.10	95.30	285.38
Class A Pan	20.40	108.50	123.90	134.16	386.95
Thornthwaite	25.38	135.50	144.90	109.98	415.76
Blaney Criddle	35.10	185.10	177.60	166.40	564.20
Hargreaves	37.50	208.01	288.00	191.36	724.87
Jensen Haise	46.32	257.30	282.00	237.12	822.74

a The Blaney -Morin -Nigeria method

Table 3c: Estimates of PET and Lysimeter maize ET during the third planting period (14th January to 16th April 1994)

Estimation method	Evapotranspiration, mm				
	Jan	Feb	Mar	Apr	Jan -Apr
ET (Lysimeter)	25.75	107.83	152.54	74.06	360.18
Penman	69.80	114.60	111.91	57.56	353.87
B.M.N.[a]	72.72	124.88	120.90	58.88	377.38
Class A Pan	99.00	138.32	124.62	58.40	420.34
Thornthwaite	85.14	160.44	179.49	88.80	513.87
Blaney Criddle	123.50	177.24	200.60	103.50	604.84
Hargreaves	138.06	218.68	246.76	131.36	734.36
Jensen Haise	172.30	292.88	308.45	164.96	938.59

a The Blaney -Morin -Nigeria method

Table:3d: Estimates of PET and Lysimeter corn ET during the fourth planting period (27th September to 28th December 1994)

Estimation method	Evapotranspiration, mm				
	Sept	Oct	Nov	Dec	Sept - Dec
ET (Lysimeter)	0.64	50.72	113.60	112.92	277.88
Penman	10.56	81.53	87.60	102.76	282.45
B.M.N.[a]	7.29	83.39	95.10	99.40	285.18
Class A Pan	13.60	108.50	123.90	144.48	390.48
Thornthwaite	16.92	135.47	144.90	188.44	415.73
Blaney Criddle	23.36	185.07	177.60	179.20	565.23
Hargreaves	25.00	208.01	288.00	206.08	667.09
Jensen Haise	30.88	257.30	282.00	255.36	825.54

a The Blaney -Morin -Nigeria method

Table 4: Comparison of Estimation Methods

Estimation Method (1)	Mean mm/day (2)	Std. Dev. (3)	Std. Error (4)	95%confidence Interval for mean (5)
Penman	3.23[a]	0.43	0.11	3.00 - 3.45
Blaney- Morin- Nigeria	3.45[a]	0.65	0.16	3.10 - 3.79
Class A Pan	4.17	0.72	0.18	3.79 - 4.56
Thornthwaite	4.95	0.64	0.16	4.61 - 5.30
Blaney Criddle	6.26	0.31	0.08	6.10 - 6.43
Hargreaves	7.44	0.64	0.16	7.11 - 7.79
Jensen - Haise	9.35	0.92	0.23	8.86 - 9.84

Values are not different (p 0.05) by Duncan's Multiple range tests

Table 5 The evaluation methods for estimating PET in comparison with actual corn ET in Port Harcourt area.

Estimation method	Intercept	Slope	Coeff. of Regression	Mean ratio	Mean Diff.	Median ratio	std	std as % of mean ratio	value	r.m.s diff mm/day
Class A pan	4.55	-0.09	0.94	1.00	0.0012	1.00	0.85	85.0	0.01	4.23
BMN	4.80	-0.18	0.94	0.82	0.73	0.86	0.82	100.0	3.35	3.48
Thornth - waite	4.97	-0.16	0.91	1.19	-0.78	1.16	0.80	67.2	-3.89	4.99
Penman	4.93	-0.23	0.90	0.77	0.95	0.82	0.60	40.0	6.29	4.80
Blaney Criddle	6.56	-0.38	0.74	1.50	-2.09	1.53	0.51	14.0	-16.24	6.26
Hargreaves	5.32	-0.15	0.80	1.78	-3.27	1.84	0.79	44.4	-16.52	7.46
Jensen-Haise	5.23	-0.11	0.81	2.24	-5.18	2.28	1.06	47.7	-19.40	9.37

R.M.S. Root Mean Square
Std Standard deviation

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