

ARTIFICIAL NEURAL NETWORK-DRIVEN FORECASTING OF MILLET YIELD BASED ON CLIMATIC INDICATORS IN KANO STATE, NIGERIA

Abdulrazak, T. K¹., Abubakar A.S²., Mohammed B.Y²., Terseer I²., & Tanko A.I^{2,3}

¹ Department of Geography, Kano University of Science and Technology, Wudil, P.M.B. 3244, Kano State Nigeria.

² Department of Geography, Federal University of Technology Minna, Niger State, Nigeria

³ Nigerian Meteorological Agency (NiMet), National Weather Forecasting and Climate Research Centre, Abuja, Nigeria

abdulrazaktijjanikura@gmail.com

Abstract

Machine learning algorithms like artificial neural networks (ANN) are capable of providing accurate predictions of crop yields based on climatic variables. Meteorological data from 1993 to 2023 and Millet yield from 2010 to 2023 were obtained from the National Aeronautics and Space Administration (NASA) and the Kano Agricultural and Rural Development Agency (KNARDA) respectively. The ANN algorithm was used in predicting Millet yield based on the dataset of the climatic variables. Seven climatic variables (Rainfall, Maximum, temperature, Minimum temperature Relative humidity, Sunshine hours, Wind speed and direction) were used as input neurons for the ANN algorithm. Three hidden neurons were used to train the ANN network in order to understand the pattern of the dataset for better prediction. The maximum prediction in Millet yield was achieved using three hidden neurons. Thus, the best fitting model for the ANN prediction was obtained with an R-squared (R^2) of 1 (100%) for the training, and validation with an R^2 of 0.99 (99%). The study indicated that the model is very reliable and statistically significant in predicting the variability of Millet yield. Therefore, based on the training and validation, it is a perfect linear graph which shows same values for both the actual and predicted variables. Findings from the study reveals that the ANN has the capacity of identifying patterns in historical data and can make prediction of Millet yield variability possible. This study therefore recommends its use in supporting the development of management practices that are best adapted to climate variability and provides an insight on how to reduce risks associated with reduction in crop yield.

Keywords:-Sorghum yield, ANN, Climatic variables, Variability, Prediction

Introduction

Climatic variability refers to variation in weather and climate variables at a given location at a point of time. It brings about change in the mean values of rainfall, temperature (Maximum and Minimum), changes in the level relative humidity, sunshine hours/duration and changes in wind direction and its speed. Climatic variability became one of the concern global issue by scientists and other stakeholders (Francis, *et. al.*, 2014). Crop production worldwide has already been affected by climatic variability (Ray *et al.*, 2020). Rainfed system of crop production is very sensitive to weather and related climatic variability. Majority of the population in developing societies depend upon rainfed agriculture which provides food for the family and income to the

people. In African continent, rainfed system of production remain essential for wellbeing of the people but the region is classified with very low adaptive capacity to climate and its related variability hence climate change posed a higher impacts to regions (Cudjoe *et al.*, 2021). Rainfed agriculture which is mainly subsistence in nature also with relatively low output faces the impacts of Climate variability (Olayide *et al.*, 2016). Rainfall and temperature are dominant variables that play a greater role toward crop development and importantly the yield (Yu *et al.*, 2014). According to Siebert and Ewert, (2014) the negative effects of climatic variability on food production are very diverse and intricate. Fluctuations in rainfall and temperature are affecting rainfed crop production (Dube&Phiri, 2013).

Impact of climatic variables due to climate change had been affecting crops yields over decades. The study area does experience variability in climatic conditions more especially during raining season which correspond to the season where farmers depend on rain to produce crop through rainfed system. Kano state is the most densely populated place of northern Nigeria in which 75% of the productive age participates directly or indirectly on agricultural activities. It's believed that most of the cereals and legumes crops are cultivated in the area.

Therefore, this paper developed a predictive model for forecasting climate related Millet yield variability in the study area. The study was limited to Kano state, it focused is on the prediction of rainfed crop yield in-relation to climatic variability. The climatic factors concerned includes: maximum and minimum temperature, rainfall, relative humidity, sunshine hours, wind direction and wind speed from 1993 -2023. While, crop studied was Cereals (Millet) record from 2010 to 2023. Millets are primarily consumed in the places where they are produced, and regarded as staple foods in most developing nations. International trading of millets is relatively limited compared to other major cereals like Sorghum and Maize. But there is a growing international interest in production of millets looking at its health advantages and resilience to climatic vagaries.

Climatic Variability and Rainfed Crop Yield

Climatic variability is predicted to greatly affect crop yield in most regions of the world (IPCC, 2014). Agriculture is one of the most weather sensitive of all human economic activities worldwide. Climatic variables affect agriculture and determine the success and equally the adequacy of food crops. Climate determines whether or not rain fed agriculture will be feasible and the type of crops that can be successfully cultivated in a given area. In Kano state, crop production served as a major source of livelihood for most rural communities since 75% of the population practice farming which is mostly rain fed agriculture and any change in climatic variables such as rainfall, temperature, wind speed and direction, sunshine duration and humidity levels are expected to affect the potential crops yields of both cereals and legumes produce under rainfed system at the end of farming season (Ndamu, *et al.*, 2014). According to Yuhanet *et al.*, (2024) studies on crop yield prediction in-relation to climatic variables is becoming an interesting arena that researchers in agricultural sector need to explore looking at it potentials in developing initiatives and programs that support socioeconomic wellbeing of the people. In that proper and accurate prediction of crop yield is very essential to the famers, agricultural institutions and the government for initiating policies that guides decision making and implementation.

Crops growth and development are affected by maximum and minimum temperature, rainfall, relative humidity, sunshine hours, wind direction and wind speed which combine to produce the

observed impacts on crops yield over an area. Each of these climatic factors has the ability to separately affect the different functions of the crops in the course of their growth and the final yield.

Millet and its Environmental Background

Millet originated in tropical western Africa some 4000 years ago. The greatest numbers of both wild and cultivated forms of this species occur in this region. From there, it differentiated into globosum race and moved to the western side, and it also differentiated into the typhoides race that reached eastern Africa and spread to India and southern Africa some 2000–3000 years ago. Pearl millet is a member of the grass family and it was originally a wild plant in Africa. The evolution of pearl millet under the pressures of drought and high temperatures imparted the ability to tolerate drought, soil toxicities and extremes of temperature more effectively than other cereals like wheat and rice. The area sown to the crop in West Africa is estimated at 12 million hectares, while in Nigeria, millet is cultivated on 5 million hectares (FOA 2014), equivalent to 20.84 percent of the 23.99 million hectares of the total arable land. Pearl millet production in Nigeria increased gradually between 1988 and 1994, reached peak in 1988 and 1990 and then declined, CBN (2010).

Germination

At optimum temperatures (25 to 30°C) and moisture, pearl millet seed germinates in 2 to 3 days. When pearl millet seed is sown in moist soil, the seed swells due to moisture absorption. The seed coat breaks and a small shoot (coleoptile) and a primary root (radicle) develops. Initially, the young seedlings take nutrients from the endosperm of the seed (Olumiyiwa, 2019).

Vegetative Stage

Seedling development occurs during the first two to four weeks, and later rapid stalk development occurs. Pearl millet often tillers, producing profuse leaf growth. There are different types of tillers primary, basal, secondary and nodal. Tillering may be extensive in sparse population particularly if good soil moisture is available. About 6 to 8 days before flowering, the boot forms a bulge in the sheath of the flag leaf (uppermost leaf). This stage is called boot leaf stage. Pearl millet usually flowers in 40 to 55 days. Some of the photoperiod sensitive types may take longer to flower, while others may not flower at all when exposed to longer day length of 14–16 hours. (Olumiyiwa, 2019)

Panicle Development

The flower structure (inflorescence) in pearl millet is a compound terminal spike, also called panicle or ear head. In cultivated pearl millets, the panicle starts developing from 22 to 28 days after germination. Each spike consists of 800–3000 spikelets, depending on the size of the spike, and each spikelet consists of two florets. Those florets which are hermaphrodite (bisexual) contain both stamens (male organs) and pistils (female organs). There are florets which only have stamens. Stamens have anthers and pistils have stigmas. Stigmas emerge first and anthers 3–4 days later. This flowering behavior called protogyny makes pearl millet a highly cross-pollinated crop. It makes both selfing and crossing easy in this crop because selfing just requires covering the spike with a paper bag when it is emerging from the boot. Crossing does not require emasculation. It just requires collecting pollen from the bagged panicles of one line and dusting it on the panicle of the other line when stigmas have fully emerged.

Flowering and Grain Filling Stage

The pearl millet seed is a caryopsis. The grain matures in 25 to 30 days after fertilization. millet seeds may be pearly white, pale yellow, brown, and gray, slate blue or purple. The shape may be

obovate, lanceolate, elliptical, hexagonal or globular. The 1000-seed mass can vary from 2.5 to 20 g, but most of the improved cultivars have 7–12 g of 1000-seed mass. (Olumiyiwa, 2019)

Physiological Maturity

Total dry weight of the plant reaches maximum at physiological maturity. Uptake of nutrients also mostly ceases at this stage. So, if there are problems like bird damage, grain molds, it is advantageous to harvest the crop at this stage. Like in sorghum, physiological maturity can be determined by the development of a small dark layer at the bottom of the grain and this occurs about 30 days after flowering. As the seed moisture at this stage will be about 20%, proper drying of the seeds is important. (Olumiyiwa, 2019).

Distribution of Millet

Area and production of millet in the world is combined with other millet crops like finger millet, foxtail millet, etc. So, separate data are not available for pearl millet. However, pearl millet is cultivated mostly in Africa (about 14 million ha) and Asia (about 12 million ha). In Asia, India has the largest area of 10 million ha. Millet accounts for about 50% of the total area under all millets in the world. Millet (*Pennisetum glaucum* (L.) R.Br.) Is one of the most extensively cultivated cereals in the world, ranking sixth after rice, wheat, maize, barley and sorghum in terms of area planted to these crops. It is a principal cereal cultivated in drought-prone semi-arid regions of Africa and the Indian subcontinent, mostly for food uses. In USA, Australia, Southern Africa, and South America, pearl millet is grown on limited scale as a forage crop. In addition to grain and forage uses, pearl millet crop residues are used as fodder, building material and fuel for cooking, particularly in dryland areas. (Olumiyiwa, 2019)

Millet crop has wide adaptability to local environments. It is a hardy crop and can be grown in areas which are very hot and dry, and on soils too poor for crops like maize and sorghum. Pearl millet is considered more efficient in utilization of soil moisture and has a higher level of heat tolerance than sorghum and maize. (Olumiyiwa, 2019). Pearl millet is usually grown with low or no external inputs; hence yields are generally very low (300–800 kg ha⁻¹ grain yield). However, when cultivated as an irrigated crop with 60–80 kg ha⁻¹ applied nitrogen, pearl millet hybrids have produced 4000–5000 kg ha⁻¹ of grain yield during the summer season in parts of India. A majority of the subsistence farmers who typically cultivate this crop are unable to take advantage of high yield potential of millet because of the lack of application of improved management practices.

Millet productivity can be increased by growing varieties/hybrids with improved tolerance to drought, resistance to diseases, and with fertilizer applications and soil moisture management. Millet can grow in a wide range of ecological conditions and yield reasonably well even under unfavorable conditions of drought stress and high temperatures. It is mostly grown in countries with hot and dry weather, quite characteristic of the arid and semi-arid environments. Millet is a warm-weather crop and grows best at 30–34°C air temperature. It is more tolerant to higher temperatures than probably any other major cultivated cereal. Millet hybrids having good seed set at air temperatures as high as 46°C are cultivated during the summer in parts of India. These useful characteristics mean that millet is finding a new niche in some unexpected places. The best temperature for the germination of millet seed is 23 to 32°C. Poor emergence and seedling growth may result, if planted before soil temperatures reach 23°C. (Gourdji, *et al.*, 2013)

The optimum rainfall requirement of millet ranges between 600 and 800 mm. But, pearl millet can be grown in areas which receive even less than 350 mm of seasonal rainfall. Prolonged spells of

warm and dry weather is detrimental to the crop, leading to reduced crop yields. At harvest time, dry and warm weather is most suitable. Although millet can respond to good moisture during its growth, it is nevertheless one of the toughest, drought-tolerant crops.

Artificial Neural Networks and Crop yield Prediction in-relation to Climatic Indicators.

Artificial neural networks (ANN) is an intelligence algorithm model technique that is use to predict the impact of certain input variables (like climatic variables) on response variable or dependent variable (Example, Crop yield), ANN is widely use because it mimic the central nervous system of a human brain. It has the ability to learn and it can be train to learn the pattern of the data set. Hence, ANN helps in predicting crop yield by learning complex and non- linear relationships between meteorological variables and crop yield data. It has the capacity of identifying patterns in historical data and makes forecast or prediction of the future yield. That is why it can handle complex relationships far better than other modeling techniques.

Researches has demonstrated that machine learning like artificial neural networks (ANN) can provide more accurate prediction on studying crop yield in-relation to climatic variables. Some of these studies include the work of Nirmitha *et al.*, (2013) who used artificial neural networks to predict rice yield in India using climate data, the climatic variables were found to have significant impacts on rice yield. The research highlighted the importance of using advanced models for better prediction. Another study by John (2025) Compared five different machine learning in predicting sorghum yield including artificial neural network (ANN), the work found that artificial neural network was among the models that presented high accurate prediction supported with a better R^2 values. Also a study by Elizondo *et al.*, (1994) that focused on predicting the yield of soya beans using machine learning (ANN), the model clearly gives better prediction when compared to other methods. Equally a study carried out in Maharashtra India that utilized climatic data between 1998-2002 were artificial neural network was employed to predict crop yield, the model indicated the potentials of ANN model toward helping famers in making a proper decision looking at the predicted yield. It is well known fact, that crop production is influence by a number of interconnected factors and makes it difficult to explain their relationship by using conventional means (Paswan and Begum 2013). Thus using artificial neural network (ANN) is recommended to handle complicated relations between different parameters and crop production. Many studies employed ANN in predicting agricultural crop yield example include (Drummond *et al.*, 1995, Jian *et al.*, 2024, Munkvold, 2004).

Description of Study Area

The study area is located between latitude $10^{\circ} 05''$ N and $12^{\circ} 45''$ N and longitude $7^{\circ} 45''$ E and $9^{\circ} 75''$ E. It shares borders with Katsina State to the North-West, Jigawa State to the North-East, Bauchi State to the South-East and Kaduna State to the South-West. It has a land area of about 20,131 km². The climate of the Kano State is the tropical dry-and-wet type, classified by Koppen as Aw. There are two distinct seasons resulting from the seasonal movement of two air masses in the region. The air masses are tropical continental which is dry and the other one is called tropical maritime air mass which is wet in nature, given birth to wet and dry season. The wet season lasts from June to September although May is sometimes humid. The dry season extends properly from mid-October of the one calendar-year to mid-May of the next. The annual mean rainfall in the region is between 800mm and 900mm. (Olofin, 2016) variations about the annual

mean value are up to ± 30 percent. More than 300mm of the rainfall is received in August alone, while the truly wet season lasts from June to September.

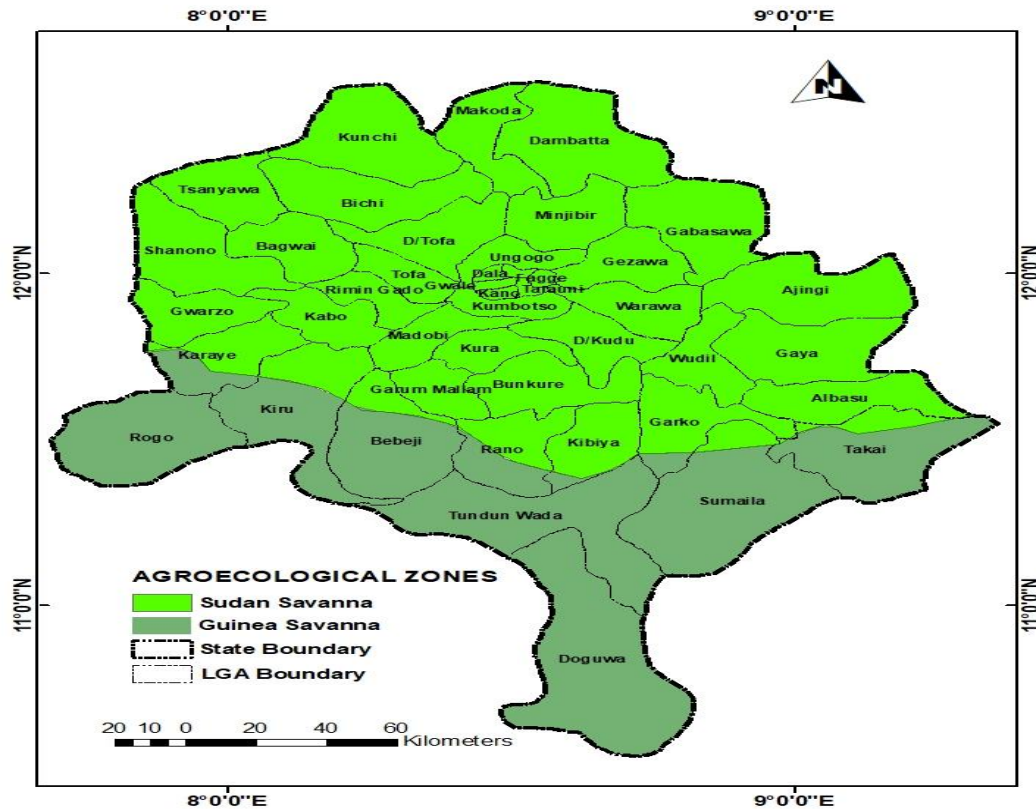


Figure 1. Kano State Showing Agroecological Zones

Source: Adopted from IITA Agroecological Map of Nigeria (2004) as used in Hassan (2023)

RESEARCH METHODS

Data Type, Sources and Collection Procedure

The quantitative (secondary) data, that is historical data for climate variables (Rainfall, Maximum temperature, Minimum temperature, Relative humidity, Sunshine hours, Wind speed and direction) for 30years (1993-2023) and Millet yield record for 13 years were collected from National Aeronautics and Space Administration (NASA) and the Kano Agricultural and Rural Development Agency (KNARDA) respectively. Several studies utilized NASA data to analyze the status of climatic variables over time, studies like that of Udehet *et al.*, (2024) and Ishaku *et al.*, (2024), equally records of agricultural yield were used because it can provide valuable insights into trends and patterns that can be use in trend analysis and prediction of crop yield.

Mean daily data of rainfall, maximum temperature, minimum temperature, relative humidity, sunshine hours, wind speed and direction data was obtained via NASA POWER Data Access Viewer (DAV <https://power.larc.nasa.gov/data-access-viewer/>) where mean annual values were derived. Annual yield records (in tons) of Millet was collected from Kano Agricultural and Rural Development Agency (KNARDA) Kano office. These data were collected on excel spread sheet for easy computation.

Data Analysis

In this study the ANN was employed to analyze the data, the data set was divided into two, 70% of the data was used for the training and 30% of the data for validation. The essence of the training is to allow the network to understand the pattern of the data set, while validation is to validate whether the train data set has been able to predict with high level of accuracy.

Results and Discussion

Artificial neural network was applied to predict crop yield of Millet, where seven climatic variables that comprises of Maximum temperature, Minimum temperature, Rainfall, Relative humidity, solar radiation, Wind speed and Wind direction were used as input variables for the ANN network. Different hidden neurons were used to train the ANN network in order to understand the pattern of the data set for better prediction.

Several ANN topologies were designed to determine the best hidden layer with the maximum prediction model. Therefore using 3 neurons, the highest prediction was achieved with an R^2 of 1 (100%) for the training and validation having an R^2 of 0.99 (99%). The training and validation also shows a perfect linear graph which indicate that the actual variable is the same as the predicted result as shown in figure 4. Some studies concluded that important climatic variable that influences annual Millet yield include rainfall, temperature and sunshine hours example Toureet *al.*, (2018).

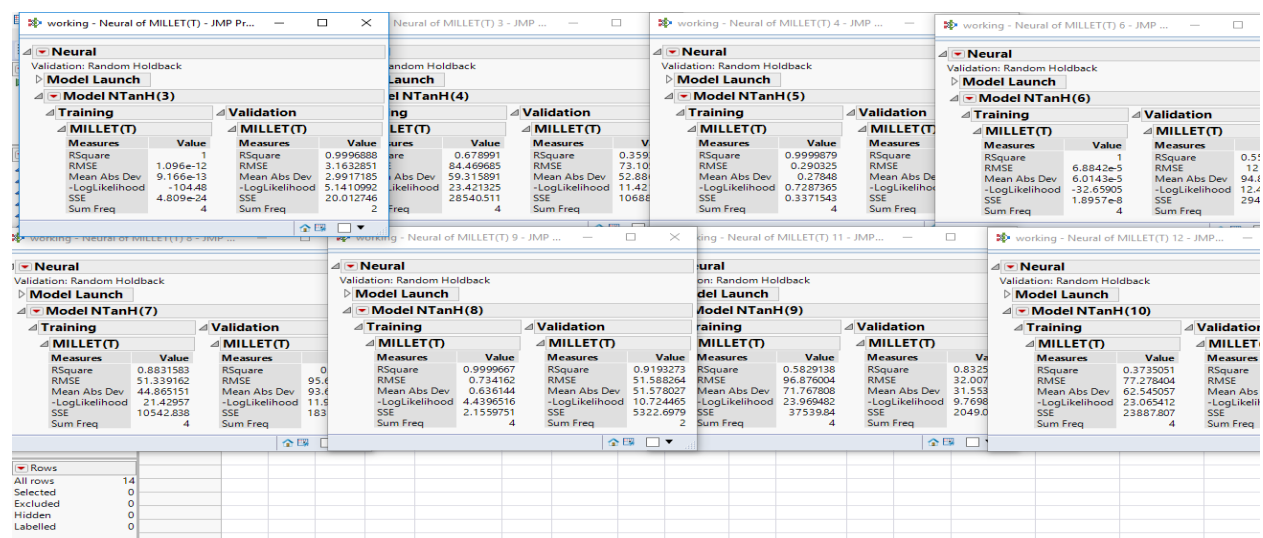


Figure 2. Showing ANN training of different neurons for predicting Millet yield

Diagram

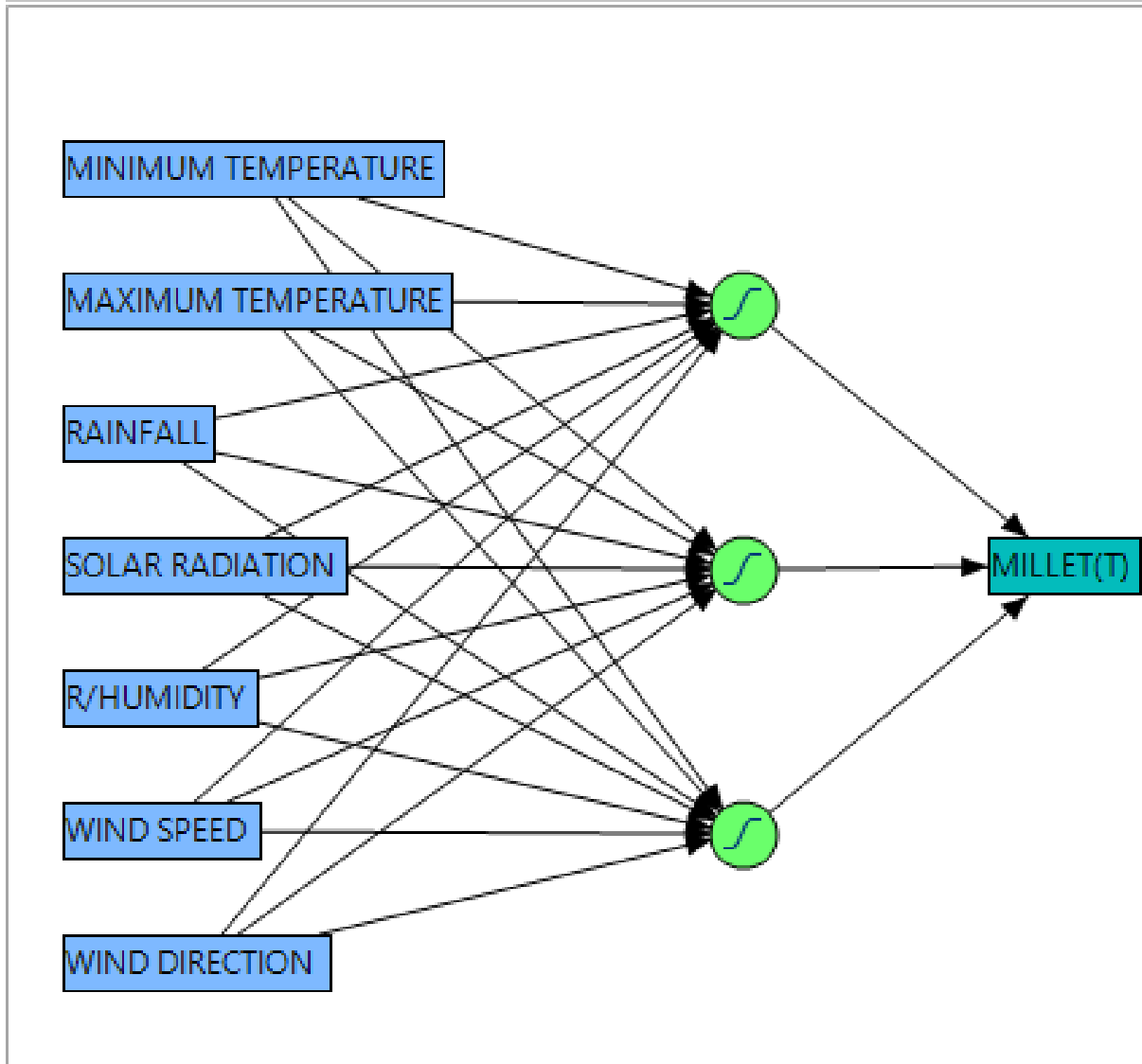


Figure 3. ANN typology showing input variables and hidden neurons for predicting Millet yield

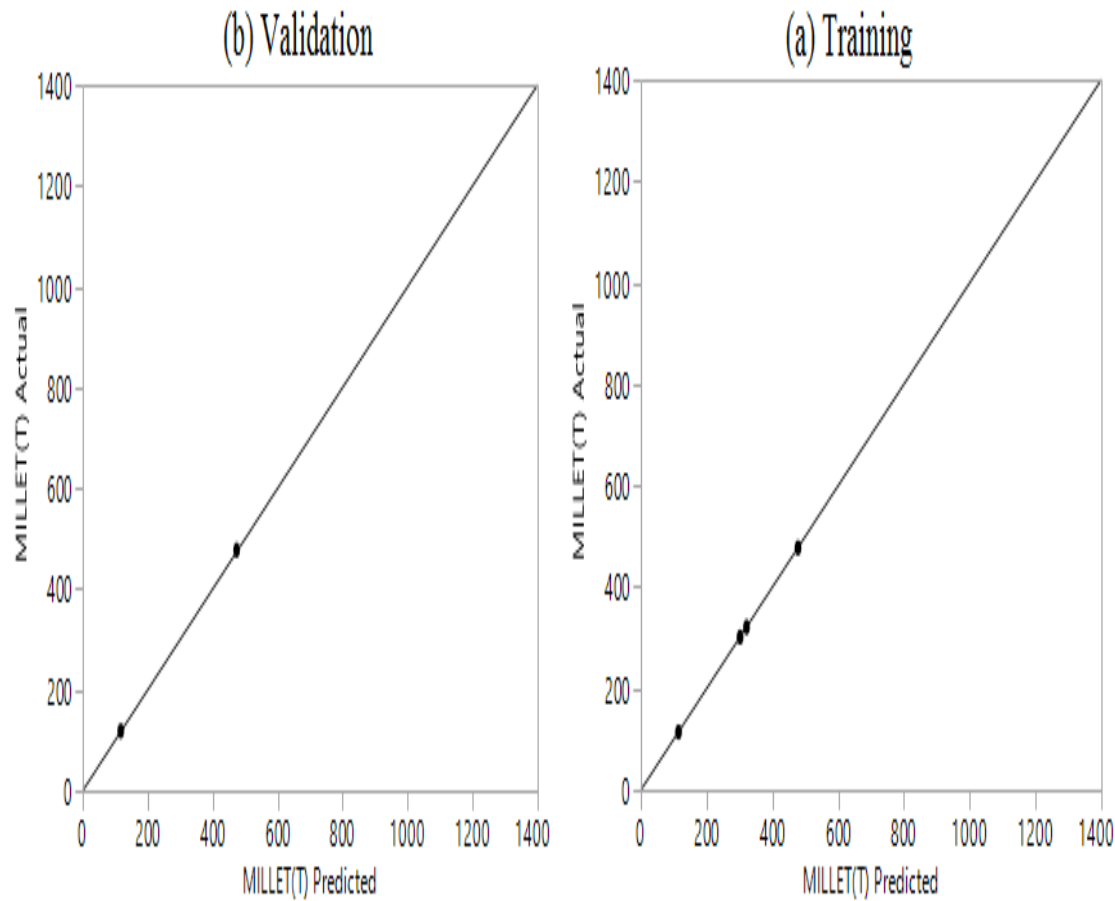


Figure 4. Showing the linear graph between the actual and predicted result of Millet (Training and Validation)

Millet needs adequate moisture during rainy season whereby less rainfall can reduce millet yield in a planting season. For a millet to grow optimally, a temperature of between 25⁰C and 35⁰C is needed, temperature of below 20⁰C can alter the growth of millet and also too much of temperature can affect the millet output. Millet requires relatively optimum humidity level with adequate sunshine hours for photosynthesis. Kano being under in the northern part of Nigeria experiences rainfall of above 900mm, high temperature during rainy season which gave birth to high humidity level supported by intense solar insolation which last for about 8hours daily provide a favorable conditions for millet to grow excellently.

A report made available by the Food and Agriculture Organization (FAO), at world scale millet production experience a significance increased from 28.33 million metric tons in 2021 to 30.80 million metric tons in 2023. India, Niger, China, Mali and Nigeria are the first five leading millet-producing countries, making a total of 60% of global production of Millet (USDA, 2025) The table below as used in Muskanet *al.*, (2025) displayed the top ten leading producing nations of Millet. Millets has been regarded as staples for local consumption in Africa, and it is gaining international recognition due to their nutritional value and tolerant to climatic variability.

Table 1: Top ten Millet Producing Nations in the World

Country Rank	Country	% of World Production	Production (1000 MT)	Area (1000 Ha)	Yield (T/Ha)
1	India	43	13,500	9,500	1.42
2	Niger	11	3,400	6,800	0.50
3	China	9	2,700	900	3.00
4	Mali	6	1,800	2,100	0.86
5	Nigeria	6	1,700	1,900	0.89
6	Ethiopia	4	1,125	455	2.47
7	Senegal	4	1,100	1,000	1.10
8	Burkina Faso	3	1,000	1,200	0.83
9	Sudan	3	1,000	2,500	0.40
10	Chad	2	700	1,180	0.59

Source:- FAOSTAT 2023

Conclusion and Recommendation

The ANN model developed in the study accurately predicted the millet yield with very high R-square and a resulting low root mean square error. The study indicated that the model is very reliable and statistically significant in predicting the variability of Millet yield. Therefore, based on the training and validation, it is a perfect linear graph which shows same values for both the actual and predicted variables. Findings from the study reveals that the ANN has the capacity of identifying patterns in historical data and can make prediction of Millet yield variability possible.

Therefore, the study recommends the use of ANN model in supporting the development of management practices that are best adapted to climate variability and provides an insight on how to reduce risks associated with reduction in crop yield.

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