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Determination of Irrigation Scheduling and Optimal Phosphorus Fertilizer Rate for Onion in Tiyo District, Arsi Zone, South Eastern Ethiopia

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Abstract:
The three-years consecutive study was carried out at the Kulumsa Agricultural Research Center (KARC), Tiyo, Arsi Zone, Southeastern Ethiopia. The objectives of the study were to determine optimal irrigation levels and phosphorus rates, as well as the interacting effect of nutrient and moisture levels on onion yield and yield quality. The experiment was arranged in a split plot Randomized Complete Block Design (RCBD) with three replications. The main plots received three irrigation levels, whereas sub-plots received five phosphorus fertilizer rates. Key growth parameters such as plant height, number of leaves per plant, bulb diameter, sugar content, average bulb weight, and marketable yield were subjected to evaluation. The results demonstrated that irrigation and phosphorus levels had a significant impact on onion growth and yield components. The study result of onion bulb yield revealed significant differences at ($p<0.05$). The highest marketable bulb yield of onion 28.08 tons ha-1 was obtained at 100% crop evapotranspiration (ETc) and 30 kg ha-1 of phosphorus application. The highest water productivity 10.38 kg/m3 result was recorded from the treatment receiving 50% ETc and 20 kg ha-1 of phosphorus. The economic analysis found that treatment 100% ETc with 30 kg ha-1 of phosphorus was more profitable, with better net benefits and significant marginal rates of return when compared to other treatments. As a result, a phosphorus rate of 30 kg/ha combined with irrigation levels of 100% and 75% ETc also gave over 100% MRR as a promising option for maximizing onion output in the study area.

Keywords: Optimum irrigation, phosphorus fertilizer rate, onion bulb yield, water productivity

INTRODUCTION

Onion (Allium cepa L.) is an important bulb crop and it is widely produced by farmers and commercial growers throughout the year for local use and export market in Ethiopia (Teshome & Bogale, 2022). Onion is valued for its distinct pungency and forms essential ingredients for flavoring varieties of dishes, sauces, soups, sandwiches and snacks as onion rings etc(Teshome & Bogale, 2022). It is popular over the local shallot because of its yield potential per unit area, availability of desirable cultivars for various uses, ease of propagation by seed, high domestic (bulb and seed) and export (bulb, cut flowers) markets in fresh and processed forms. Ethiopia has high potential to benefit from onion production. The demand for onion increases from time to time for its high potential to benefit from onion production. The demand for onion increases from time to time because of its high bulb yield, seed and flower production potential (Lemma and Shimelis, 2003).

In most irrigable lands, horticultural crops in general and vegetables in particular, play an important role in contributing to household food security and income (Agumas et al., 2014). Vegetables being cash crops, with high nutritional value, generate income for the poor households. Higher profits can be achieved by increasing the production of a particular vegetable throughout the year when an efficient irrigation system is used (Yitagesu Kuma & Tigist Alemu, 2015). Onions have a shallow, sparsely branched root system with most roots in the top 30 cm of soil. Rooting density decreases with soil depth. Thus, it is important to maintain nutrient and soil moisture within the shallow rooting area (Teshome & Bogale, 2022).

Phosphorus fertilizer is one the most complex in production in many tropical soils, due to low native content and high phosphorus immobilization within the soil. Phosphorus is essential for root development when availability is limited, plant growth is usually reduced. In onions, phosphorus deficiencies reduce root and leaf growth, bulb size, and yield and also delay maturation(Ali & Gebeyehu, 2019). In soils that are moderately low in phosphorus, onion growth and yield can be enhanced by applying phosphorus. Onions are more susceptible to nutrient deficiencies than most crop plants because of their shallow and unbranched root system, hence they require and often respond well to the addition of fertilizer (Brewester,1994). Onion is grown in most parts of Ethiopia but, a lot of constraints have contributed to the low yield. Phosphorus deficiency is one of the constraints to onion production in many tropical soils. The use of sub-optimal phosphorus fertilizer is one of the prominent to mention. Still, well recommended rate of phosphorus fertilizer is not well identified(Teshome & Bogale, 2022). The low productivity of onions in Ethiopia could be ascribed to a host of agronomic, environmental, and management factors, with irrigation and fertilization being the important ones (Fekadu and Dandena,2006; Muluneh et al.,2019). Presently, both water and nutrients are not properly managed, resulting in crop yields far below their potential. Onions have a large water requirement and the shallow root system is, generally, more susceptible to water stress as compared to other crops. Also, onions producing large biomass would have high nutrient requirements, especially nitrogen and Phosphorus (Drechsel et al., 2015). Therefore, proper water and nutrient management is considered one of the strategies for enhancing the productivity of onions. There is still little or no information on the irrigation scheduling and optimum fertilizer P rate for onion production in the study area. Furthermore, the optimum nutrient rate, preferably, needs to be based on the interactive effect of irrigation and nutrients, as both inputs are linked, and failure to manage one affects the other, or improvement in one could enhance the efficiency of the other. Therefore, the objectives of this study were to determine appropriate irrigation levels and phosphorus rates and identify the interactive effect of nutrient and moisture levels on yield and yield quality of onion under the agroecological conditions of Tiyo, Arsi Zone, southern Eastern Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

A field experiment was implemented at Kulumsa Agricultural Research Center (KARC) for three consecutive years (2020/21 to 2022/23). KARC is located in Tiyo district of Arsi Zone, Oromia regional state, Southeastern Ethiopia. The soil type is predominantly Luvisol/eutricnitosols with a good drainage system (Tafesse, 2003). The mean annual maximum temperature is 230C and monthly values range between 21 and 25 oC. The mean annual minimum temperature is 10 oC and monthly values range between 8 and 12 oC. The experimental site is located at a latitude of 08⁰00'8.55'' and a longitude of 039⁰09'23.7'' and situated at an altitude of 2192m asl.

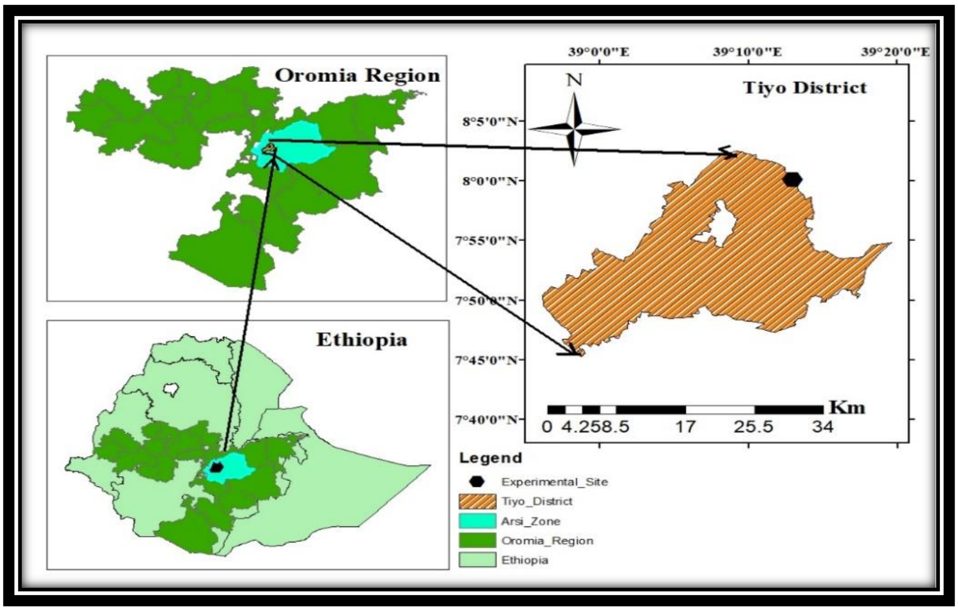

Figure 1: Map of the study area

The area receives an average annual rainfall of 821mm and is characterized by unimodal rainfall pattern. The study area receives peak season rainfall from July to August. The average annual minimum and maximum temperatures are 9.9 and 23.1°C, respectively. Effective rainfall and potential evapotranspiration of the cropping season at the study area is shown in figure (2).

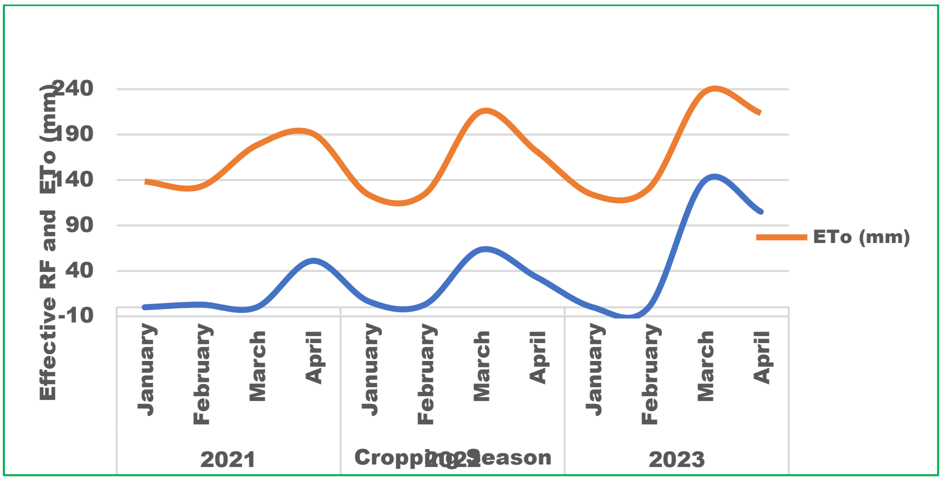

Figure 2: Effective rain fall and potential evapotranspiration of the cropping season

Experimental Design and Procedures

The experiment was laid out in RCBD with a split-plot arrangement. The treatments were randomized both at the main and sub-plot levels with three replications. The irrigation levels were in the main plot while phosphorus fertilizer rate treatments were assigned to the subplots.

Table 1: Description of treatment combinations

Levels	Phosphorus rate (kg/ha)				
	0	10	20	30	40
100% ETc	T1	T2	T3	T4	T5
75% ETc	T6	T7	T8	T9	T10
50% ETc	T11	T12	T13	T14	T15

Agronomic Data Collection and Interpretations

Onion seedlings (*Bombay Red variety)* were raised following proper management practices as suggested by EARO (2004). Seedlings were hardened before being transplanted to the experimental field to enable them to withstand the field conditions. The 45 days healthy and vigorous seedlings were transplanted. After transplanting, three full irrigations were applied uniformly to all plots with three days intervals, to ensure good plant establishment. Immediately after crop establishment, irrigation was applied to each plot according to the treatment requirement using a Parshall flume. Urea was used as a source of N; half of the N dose was applied at the time of transplanting and the remaining half was side-dressed after 45 days of transplanting. The P fertilizer was applied as per treatment to all plots at the time of transplanting using triple superphosphate (TSP). The uniform field management was carried out on all plots as per the recommendations of EARO (2004).

The inter and intra-row spacing in the experimental plots was determined using the recommended agronomic value for onion. Onion crop was transplanted on both sides of the ridge with 40 cm, 20 cm and 5 cm spacing of row plant (plant row spacing across furrow was 40 cm, across the ridge was 20 cm and along the ridge 5 cm between plants). The experimental field was divided into 45 plots and each plot size was 3m*3.5m in dimension (10.5 m^2) area to accommodate six furrows with a spacing of 60 cm and 3.5 m in length. Each plot consisted of five ridges and six furrows. A field channel was constructed for each block to irrigate the field.

Yield and Yield Components:

Growth Parameters of Onion:

The height of five randomly selected plants was measured from the ground level to the tip of the longest matured leaf at physiological maturity. The average number of leaves was counted from five randomly selected plants at physiological maturity.

At physiological maturity, the diameter of the bulbs of five randomly selected plants in each treatment was measured. The randomly selected onion bulbs were pressed into juices, and the refractometer reading was recorded when the liquids were placed into the refractometer. The total soluble solid content was measured in Brix. A digital balance was used to record the average weight of randomly selected matured bulbs from each plot, and a mean was reported. The weights of medium- to large-sized (20–160 g) bulbs from the three central rows that were free of disease, mechanical damage, and insect pests were converted to tons/ha to determine the marketable bulb production.

Soil Analysis:

Representative soil samples were taken from the experimental site for chemical analysis (PH, EC, CEC, total available N, OC, and OM) and physical properties (BD, Texture, FC, and PWP). Soil moisture was measured before and after irrigation using the gravimetric method.

Crop Water Requirement, Water Productivity and Yield Response Factor

Crop water requirement (CWR):

Crop water requirement (ETc) was calculated from climatic data integrating the effect of crop characteristics into reference crop evapotranspiration. FAO Penman-Monteith method was used to determine reference crop evapotranspiration (ETo). The crop coefficients (Kc), were utilized to relate ETc to ETo using the following equation:

$$ETc = ETo * Kc \quad (1)$$

where: ETc = crop evapotranspiration (mm/day), ETo = reference crop evapotranspiration (mm/day) and Kc = crop coefficient.

Irrigation Requirement (IR) was calculated using the following equation:

$$IR = CWR - \text{ Effective rainfall} \quad (2)$$

IR in mm, CWR in mm and effective rainfall, which is part of the rainfall that enters into the soil and is made available for crop production in mm.

Irrigation scheduling was worked out using Cropwat 8.0 software. One of the computing approaches in the model for optimal irrigation scheduling with no yield reduction is the irrigation applied at 100% readily available soil moisture depletion to refill the soil to its field capacity. The readily available water (RAW) was computed by the following formula:

$$RAW = P * TAW \quad (3)$$

where RAW in mm, P is in fraction for allowable soil moisture depletion for no stress, and TAW is total available water in mm.

The total Available Soil Water (TAW) was computed from the soil moisture content at field capacity (FC) and permanent wilting point (PWP) using the following expression:

$$TAW = \frac{FC - PWP}{100\rho} * (Bd * Dz) \quad (4)$$

Where FC and PWP are soil moisture content at field capacity in % on a weight basis, B_d is the bulk density of the soil in gm/cm^3, the ρ density of the water in gm/cm^3 and D_z is the maximum effective root zone depth in mm.

Soil bulk density was determined by taking undisturbed soil samples from an effective root zone at 20 cm intervals using a core sampler. Soil samples were oven-dried for 24 hours at a temperature of 105°C. Then, bulk density (ρb) was determined as equation (5):

$$Bd = \frac{Ms}{Vs} \quad (5)$$

where B_d = Soil bulk density (g/cm^3), Ms = the mass of soil after oven-dry (g) and Vs = bulk volume of soil (cm^3).

The gross irrigation requirement, IR_g, in a particular event, was computed from the expression:

$$IRg = \frac{CWR}{Ea} \quad (6)$$

Where IRg is the gross irrigation requirement in mm, CWR is crop water requirement (mm/day) and Ea is the irrigation water application efficiency in fraction.

The time required to deliver the desired depth of water into each plot was calculated using the following equation:

$$\mathrm{T} = \frac{\mathrm{IRg} * \mathrm{w} * \mathrm{l}}{60\mathrm{q}} \quad (7)$$

where IRg is gross irrigation requirement in mm *t* is application time (min), *l* is plot furrow length (m), *w* is plot width (m), and *q* is flow rate (l/s) at a specific Parshall flume head.

Water Productivity (WP)

Water productivity was estimated as a ratio of bulb yield to the total ETc through the growing season and calculated using the following equation (8).

$$\mathrm{WP} = (\mathrm{Y}/\mathrm{ET}) \quad (8)$$

Where, Water productivity is (kg/m^3), Y is crop yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Yield Response Factor (Ky)

The yield response factor (Ky) was estimated from the relationship equation (9).

$$\left[1 - \left(\frac{Ya}{Ym}\right)\right] = Ky\left[1 - \left(\frac{ETa}{ETm}\right)\right] \quad (9)$$

Where, Ya=Actual harvested yield, Ym=Maximum harvested yield, Ky=Yield response factor, ETa=Actual evapotranspiration and ETm=Maximum evapotranspiration

The Ky values are crop-specific and vary over the growing season according to growth stages with: Ky>1: crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced because of stress. Ky<1 the crop is more tolerant to water deficit and recovers partially from stress exhibiting less than proportional reductions in yield with reduced water use. Ky=1: yield reduction is directly proportional to reduced water use.

Statistical Data Analysis

Yield and yield component and water productivity data were subjected to statistical analysis using the R-Software package. Means separation was carried out using the least significance difference (LSD) test at a 5% probability level.

Partial Budget Analysis

The dominance analysis method, employed to identify potentially profitable treatments, involves listing treatments in ascending order of varying costs. A treatment is deemed dominated if its net benefits are less than or equal to treatments with lower varying costs. The treatments selected through this approach are termed dominant treatments. In evaluating pairs of ranked undominated treatments, a percentage marginal rate of return (% MRR) is computed. The % MRR between any pair of dominated treatments signifies the return per unit of investment in crop management practices, expressed as a percentage. The calculation of MRR (%) follows the CIMMYT 1988 methodology. To be considered a viable option for farmers, a treatment must have a marginal rate of return (MRR) of at least 100%.

Hence, a minimum acceptable rate of return was set at 100%. The economic analysis of phosphorus fertilizer involved utilizing partial budget analysis, taking into account the overall connection between phosphorus fertilizer rates and onion yield per hectare. Employing the CIMMYT procedure, the partial budget analysis involved examining total revenue, total variable cost, total fixed cost, total cost, net income, and benefit-cost ratio for each treatment. The economic analysis focused on fixed and variable costs.

The evaluation was conducted to determine the local market price of onions. According to the assessment, the price of 1 kg of onions was 50 ETB at the field level. For calculating the labor cost, the rate for human labor was set at 150 ETB in the field. The net income (NI) in ETB/ha derived from the onion crop was calculated by subtracting the total cost (TC) in ETB/ha from the total return (TR) in ETB/ha obtained from onion sales, following the approach outlined by Kuboja and Temu (2013).

$$\mathrm{NI} = \mathrm{TR} - \mathrm{TVC} \tag{9}$$

Total cost (TC) is the combination of fixed costs (FC) and variable costs (VC). Fixed costs (FC) encompass expenses that remain constant across different fertilizer treatments, including onion seeds, fertilizer, and land rent.

Conversely, variable costs were different between fertilizer treatments and included expenses like fertilizer and labor. The benefit-cost ratio (BCR) for each treatment was calculated as the ratio of the net income (NI) earned to the total cost (TC) incurred as follows:

$$\mathrm{BCR} = \mathrm{NI}/\mathrm{TC} \tag{10}$$

RESULT AND DISCUSSION

Soil Physical and Chemical Properties of the Experimental Site

Some selected soil physical and chemical properties of the experimental site l were presented in Table 2. Percent of particle size determination revealed that the soil texture of the study area is sandy clay loam. The mean bulk density of soil in the study area was 1.25g/cm^3. The pH was computed by Potentiometry (1:2.5 soil: water ratio), where total nitrogen was calculated by Kjeldahl method, OC and OM were analyzed by Walkley and Black while available phosphorus was analyzed by Bray-II method.

The mean pH, TN, OC, OM and Available P of the soil of the study area were 6.06, 0.11%, 1.45%, 2.51% and 11.12 mg/kg, respectively. The moisture content at field capacity, permanent wilting point, and total available water were 33.6, 21.8%, and 11.8% respectively.

Table 2: Physical and chemical properties of the experimental site

<table>
<tr><td colspan="8">Physical properties</td></tr>
<tr><td>BD (g/cm³)</td><td colspan="3">Texture</td><td>Soil type</td><td>FC (%)</td><td>PWP (%)</td><td>TAW</td></tr>
<tr><td rowspan="2">1.25</td><td>Sand</td><td>Silt</td><td>Clay</td><td rowspan="2">Sandy clay loam</td><td rowspan="2">33.60</td><td rowspan="2">21,8</td><td rowspan="2">11.8</td></tr>
<tr><td>52</td><td>27</td><td>21</td></tr>
<tr><td colspan="8">Chemical properties</td></tr>
<tr><td>pH</td><td>TN (%)</td><td colspan="2">OC (%)</td><td colspan="2">OM (%)</td><td colspan="2">Av. P (mg/Kg)</td></tr>
<tr><td>6.06</td><td>0.11</td><td colspan="2">1.45</td><td colspan="2">2.51</td><td colspan="2">11.12</td></tr>
</table>

Yield and Yield Component of Onion

Plant Height, Leaves Number and Bulb Diameter of Onion:

The statistical analysis showed that the plant height of onion was significantly ($P < 0.05$) influenced by the variation of irrigation levels and phosphorus rate application. The result of the study revealed that the longest plant height 52.15cm was recorded from the application of 100% ETc and 30 kg of P per ha. The shortest plant height (40.56 cm) was recorded from an experimental plot treated with 50% ETc and 0kg of P per ha. The increase in plant height with increased irrigation water could be mainly due to better availability of soil moisture that has enhanced the vegetative growth of plants by increasing cell division and elongation. The study findings were consistent with those of Ramada and Ramanathan (2017) on onions. The increasing plant height with adequate depth of irrigation application also indicates the favorable effect of water in maintaining the cell's turgor pressure, which is the major prerequisite for growth. On the contrary, the shortening of plant height under soil moisture stress may be due to stomatal closure and reduced CO_2 and nutrient uptake by the plants and, hence, photosynthesis and other bio-chemical processes hampered, affecting plant growth (El-Noemani et al., 2009).

The analysis variance showed that the number of leaves of onion was significantly affected by irrigation levels and phosphorus fertilizer rates (Table 3). The maximum number of leaves (15) was recorded from the experimental plot treated with 100% ETc and 40 kg Phosphorus per hectare followed by 100% ETc and 30 kg P ha^{-1}. At optimum irrigation levels, increasing the Phosphorus rate increases the number of leaves of onion. This might be because phosphorus is an essential component of nucleic acids, phospholipids and some amino acids and absorbed phosphorus helped a direct stimulation of cellular activity in roots and leaves, it is useful for the process of cell division and meristematic growth and the net assimilation rate of phosphorus fed plants were accelerated by their increased content and the absorbed phosphorus helped the formation of food reserves due to higher photosynthetic activity so, therefore, increases of the number of leaves. Similar results were found by Horneck (1999) and Singh et al., (2000). The lowest number of leaves (6.95) was recorded experimental plot treated with 50% of ETc and 0 kg ha^{-1}.

The higher leaf number per plant resulting from the application of 100% ETc irrigation level is due to the irrigation effect that facilitates nutrient availability and photosynthesis for the undisrupted growth of the plant. Similarly, the reduced number of leaves per plant at 50% ETc of irrigation level or depth is attributed to the effects of water stress on cell expansion (Abbey and Joyce, 2004). This indicated that when plants respond to water stress by closing their stomata to slow down water loss by transpiration, gas exchange within the leaf is limited; consequently, photosynthesis and growth would slow down. The result is also in agreement with the findings of Ramada and Ramanathan (2017) who found that leaf numbers had a linear correlation with the availability of soil moisture.

Bulb diameter was significantly ($P < 0.05$) affected by the amount of irrigation and phosphorus levels (Table 3). Maximum bulb diameter of 6.28 cm was recorded from the plot received 100% ETc with 30 kg/ha of phosphorus, followed by 100% ETc with 40 kg/ha phosphorus, 75% ETc with 30 kg/ha phosphorus, 50% ETc with 30 kg/ha Phosphorus which were statistical the same to the superior treatment. The lowest Bulb of 3.41 cm diameter was recorded by the application of 50% ETc with 0 kg/ha P. However, statistically not different with the treatment receiving 75% ETc and 0 kg/ha P. The results indicated that bulb diameter varied proportionally with the irrigation water applied and phosphorus level. The relation between diameter and irrigation water applied indicates that an increase in bulb diameter in different treatments was attributed to an increase in the application of water, hence water applied influences onion bulb size.

Singh et al., (2000) found similar results. The higher phosphorus rise in bulb diameter could be attributed to the phosphorus-improving carbohydrate content of the plants and extending root growth, which in turn raised bulb diameter. These findings are consistent with the findings of Kumar et al. (2007b), who found that irrigation at 1.20 Ep resulted in the largest bulb size. Similarly, David et al. (2016) observed that a greater level of irrigation 1.0 IW no water stress throughout the growing stage resulted in maximum bulb diameter, which is similar to the current conclusion.

Table 3: Effects of irrigation and phosphorus levels on plant height, leaves number and bulb diameters

Treatments	Plant Height (cm)	Leaves Number	Bulb diameters (cm)
100% ETC*0 P	44.70^{def}	9.61^{efg}	4.31^{fg}
100% ETC*10 P	46.90^{bcde}	12.05^{bcd}	5.17^{de}
100% ETC*20 P	50.18^{ab}	13.13^{ab}	5.61^{bcd}
100% ETC*30 P	52.15^{a}	14.55^{a}	6.28^{a}
100% ETC* 40 P	51.50^{a}	14.90^{a}	5.92^{ab}
75% ETC*0 P	43.36^{efg}	8.54^{fgh}	3.80^{gh}
75% ETC*10 P	45.77^{cdef}	9.87^{defg}	4.73^{ef}
75% ETC*20 P	48.60^{abc}	10.80^{bcdef}	5.52^{bcd}
75% ETC*30 P	52.03^{a}	12.07^{bcd}	6.00^{ab}
75% ETC* 40 P	49.83^{ab}	12.80^{abc}	5.78^{abc}
50% ETC*0 P	40.56^{g}	6.95^{h}	3.41^{h}
50% ETC*10 P	42.89^{fg}	8.37^{gh}	4.31^{fg}
50% ETC* 20 P	47.89^{bcd}	9.69^{defg}	5.29^{cde}
50% ETC* 30 P	49.85^{ab}	11.00^{bcde}	6.04^{ab}
50% ETC* 40 P	49.10^{abc}	10.47^{cdefg}	5.72^{abcd}
LSD (0.05)	**3.61**	**2.41**	**0.56**
CV (%)	**5.80**	**9.70**	**8.30**

Mean values in columns and rows followed by the same letter are statistically not different at $P< 0.05$, LSD = least significant difference; CV= coefficient of variation in percent.

Total Soluble Sugar:

The interaction of irrigation levels and phosphorus rates did not affect the total soluble sugar content (TSS) of onion. However, phosphorus rates had a substantial effect on onion TSS. The maximum TSS value of 15.47 °Brix was observed in the application of 40 kg ha^{-1} of p, while the lowest TSS value of 11.88 °Brix was obtained in the control treatments (Table 4).

Table 4: Effects of irrigation and phosphorus levels on TSS

Irrigation Levels	TSS (°Brix)
100% of ETc	14.17^{a}
75% of ETc	13.87^{a}
50% of ETc	13.91^{a}
LSD (0.05)	**NS**
CV (a) in %	**20.69**
Phosphorus rates (kg/ha)	
0	11.87^{d}

10	13.19^{c}
20	14.17^{b}
30	15.22^{a}
40	15.47^{a}
LSD (0.05)	0.96
CV (b) in %	7.05

Mean values in columns and rows followed by the same letter are statistically not different at P< 0.05, LSD = least significant difference; CV= coefficient of variation in percent.

Average Bulb Weight and Marketable Bulb Yield:

Average Bulb Weight:

The result of the study showed that average bulb weight was significantly (P<0.05) affected by irrigation levels and phosphorus rates. A maximum average bulb weight of 94.53g was recorded from the application of 100% ETc with 30 kg P ha^{-1} followed by 93.23g of average bulb yield recorded from the application of 100% ETc with 40 kg ha^{-1}P, while the lowest average bulb weight of 63.61g was observed in plots received 50% of ETc with 0 kg ha^{-1}P (Table 3.5). This finding is in line with Tesfaye's (2009) result. It could be because the phosphorus boosted the carbohydrate content of the plants and extended root growth, which increased the number of blubs and blub size, increasing bulb weight.

Marketable Bulb Yield:

A statistically significant variation in onion yield was observed across the experiments, with a notable difference (P<0.05). The highest yield of the marketable yield of 28.08 tons/ha was recorded at 100% of ETc with 30 kg ha^{-1} P. This treatment was found statistically equivalent to treatment received 100% of ETc with 40 kg ha^{-1} P. Conversely, the lowest 17.72 tons/ha marketable yield of onion was observed in the 50% ETc without phosphorus application (Table 5). This outcome suggests that an increase in irrigation levels and phosphorus contributes to enhanced vegetative growth in the plants. This improvement results in a higher average assimilate available for storage and an increased average bulb weight, ultimately leading to a higher marketable onion yield According to Fairhust et al. (1999), phosphorus is necessary for root growth, which leads to the absorption of water and other nutrients and a rise in the weight of fresh bulbs. According to Aster (2009), applying phosphorus level has a favorable and significant impact on bulb length, bulb diameter, average bulb weight, dry matter content, marketable yield, and total bulb yield.

Table 5: Irrigation and phosphorus levels on average bulb weight and marketable bulb yield

Treatments	Average bulb weight (gm)	Marketable bulb yield (t/ha)
100% ETC*0 P	76.60^{def}	19.11^{i}
100% ETC*10 P	83.75^{abcd}	21.70^{fg}
100% ETC*20 P	91.94^{ab}	24.68^{c}
100% ETC*30 P	94.53^{a}	28.08^{a}
100% ETC*40 P	93.23^{a}	26.75^{ab}
75% ETC*0 P	69.13^{fg}	18.74^{ij}
75% ETC*10 P	76.55^{def}	20.50^{gh}
75% ETC*20 P	83.88^{abcd}	23.20^{de}
75% ETC*30 P	88.40^{abc}	25.52^{bc}
75% ETC* 40 P	80.97^{bcde}	24.20^{cd}
50% ETC*0 P	63.61^{g}	17.72^{j}
50% ETC*10 P	71.02^{efg}	19.24^{hi}

50% ETC* 20 P	78.57 cdef	21.91 efg
50% ETC* 30 P	86.77 abcd	22.92 def
50% ETC* 40 P	81.53 bcde	22.28 ef
LSD (0.05)	**11.57**	**1.36**
CV (%)	**8.87**	**3.60**

Means values in columns and rows followed by the same letter are statistically not significantly different at P< 0.05, LSD = least significant difference; CV= coefficient of variation in percent.

Crop Water Requirements, Water Productivity and Yield Response Factor

Crop Water Requirement (CWR):

Crop water required was calculated using Cropwat 8 and the computed irrigation amount was applied to meet crop water requirements under the dry conditions. During the growing season 441mm, 331 and 220mm for 100%, 75%, and 50%, crop evapotranspiration (ETc) was applied respectively. It is very important to notice that about 25% and 50% of ETc was saved when 75% and 50%Etc of water were applied in comparison with optimal irrigation treatment (100%ETc). This result is in agreement with the findings of Igbadun et al. (2012) who showed that the water needs of onion crops reduced by about 20% with an increase in irrigation deficit of 50% of reference evapotranspiration.

Water Productivity (WP):

The analysis of variance showed that the interaction of irrigation levels and phosphorus rates had a significant effect on the water productivity (WP) of Onion at P<0.05. The highest WP of 10.38kg/m^3 was obtained from the application of 50% of ETc with 20 kg P ha^{-1} and statistically different for all other treatments except treatment receiving 50% of ETc with 30 kg ha^{-1} P. The lowest WP of 4.33 kg/m^3 was obtained from the treatment receiving 100% of ETc with 0 kg P ha^{-1}. This treatment was significantly different from all other treatments except 100% of ETc with 10 kg P ha^{-1}. This indicated that irrigating with 50% of ETc level resulted in higher WP than irrigating with 100% of ETc. As shown in Table 6, the WP decreased as the irrigation amounts increased from 50% to 100% ETc. This could be due to an improvement in yield when the amount of irrigation water was increased while maintaining favorable soil moisture conditions throughout the cropping season. These results agree with that of Teferi (2015) who reported a higher mean value of irrigation water use efficiency was observed under the drip method with a mean value of 7.1 kg m^{-3} which is 33.8% higher than that obtained in the furrow method (4.7 kg m^{-3}).

Yield Response Factor (Ky):

The observed yield response factors (Ky) result of onion for irrigation and N fertilizer level ranged between 0.00 and 1.37. According to Kirda, et al. (2000) the Ky value for field crops goes from 0.2 to 1.15 which agrees with the reported result by Watkinson (2008). From the study result of Table 6 the highest Ky was 1.37 attained at the treatment 75% ETC*0 kg/ha P (irrigating 75%ETc without N fertilizer). The higher Ky values could be an indication of the severity of water deficit and P fertilizer rate at onion bulb yield. The lowest result of yield response factors of 0 and 0.40 was observed at the treatment receiving 50%ETc*30kg/ha P followed by 75% ETC*30kg/ha P, respectively. This demonstrated the optimal response of water and fertilizer amount on onion yield. According to the results of Table 5, a moisture deficit of more than 25% combined with a fertilizer rate of less than 10 kg/ha P results in a yield reduction of 28.47 to 34.61%. (Table 6).

Table 6: Crop and irrigation water requirement, water productivity, and yield response factor of onion

Treatment	kg/ha	ETC (mm)	WP (kg/m^3)	Relative Water Saved (%)	Relative Yield Reduction (%)	Yield Response Factor (ky)
100% ETC*0 P	19,110	441.6	4.33	-	33.32	-
100% ETC*10 P	21,700	441.6	4.91	-	24.28	-
100% ETC*20 P	24,680	441.6	5.59	-	13.89	-
100% ETC*30 P	28,080	441.6	6.36	-	-	-
100% ETC*40 P	26,750	441.6	6.06	-	6.66	-
75% ETC*0 P	18,740	331.2	5.66	25.00	34.61	1.37
75% ETC*10 P	20,500	331.2	6.19	25.00	28.47	1.14
75% ETC*20 P	23,200	331.2	7.00	25.00	19.05	0.76
75% ETC*30 P	25,520	331.2	7.71	25.00	10.96	0.44
75% ETC* 40 P	24,200	331.2	7.31	25.00	15.56	0.62
50% ETC*0 P	17,720	220.8	8.03	50.00	38.17	0.76
50% ETC*10 P	19,240	220.8	8.71	50.00	32.87	0.66
50% ETC* 20 P	21,910	220.8	9.92	50.00	23.55	0.47
50% ETC* 30 P	22,920	220.8	10.38	50.00	20.03	0.40
50% ETC* 40 P	22,280	220.8	10.09	50.00	22.26	0.45

Partial Budget Analysis

An economic assessment was conducted utilizing partial budget analysis, dominance, and marginal rate of return. The onion bulb was valued based on the average market price over three consecutive production years. The average cost of urea, and TSP was 42 birr per kg. A daily wage rate of 150 birr per person was considered. The partial budget analysis employed concepts such as gross field benefit (GFB), total variable cost (TVC), total fixed cost (TFC), and net benefit (NB) (CIMMYT,1988).

The economic comparison of the data in Table (7) reveals that the direct impact of irrigation level and phosphorus fertilizer rate significantly increased net income (NI) per hectare per season compared to the absolute control. The treatment 100%ETc*40 kg/ha P incurred the highest total cost (16,522.00ETB), while the control (50%ETc*0 kg/ha P) had the lowest variable cost (6400ETB). The economic analysis highlighted (100%ETc*30 kg/ha P) as the most economically viable treatment, exhibiting a high optimal net benefit. The marginal rate of return above 100%, deemed acceptable to farmers (CIMMYT, 1988), was notably high for treatments receiving 30, 20 and 10 kg/ha P at all levels of irrigation amount. Consequently, 100%ETc*30 kg/ha P application produced the highest net benefits and marginal rate of return compared to other treatments. In conclusion, farmers in the study area benefited economically from applying 100%ETc*30 kg/ha P and 75%ETc*30 kg/ha P or 100%ETc*20 kg/ha P rather than choosing for the other treatments which are not economically viable for onion production under irrigated condition.

Table 7: Partial budget analysis based on mean values for onion production using different levels of N fertilizer and irrigation amount at Kulumsa

ETC*FR	Gross Return (ETB)	TVC (ETB/ha)	Net Return (ETB/ha)	MRR (%)
100ETc*0P	515970	6,400	509,570.00	-
100ETc*10P	585900	8,920.00	576,980.00	2675
100ETc*20P	666360	11,482.00	654,878.00	3041
100ETc*30P	758160	4,002.00	744,158.00	**3543**

100ETc*40P	722250	16,522.00	705,728.00	D
75ETc*0P	505980	4,800.00	501,180.00	-
75ETc*10P	553500	7,320.00	546,180.00	1786
75ETc*20P	626400	9,882.00	616,518.00	2745
75ETc*30P	689040	12,402.00	676,638.00	2386
75ETc*40P	653400	4,922.00	638,478.00	D
50ETc*0P	478440	3,200.00	475,240.00	-
50ETc*10P	519480	5,720.00	513,760.00	1529
50ETc*20P	591570	8,282.00	583,288.00	2714
50ETc*30P	618840	10,802.00	608,038.00	982
50ETc*40P	601560	13,322.00	588,238.00	D

CONCLUSION

The study was carried out at the Kulumsa Agricultural Research Centre (KARC) in Tiyo, Arsi Zone, Southeastern Ethiopia. The objectives of this research were to determine optimal irrigation levels and phosphorus rates, as well as the interacting effect of nutrient and moisture levels on onion yield and yield quality. The experiment was arranged in a Randomized Complete Block Design (RCBD) split plot with three replications. The experiment utilized three irrigation levels (100%, 75%, and 50% ETc) were paired with five phosphorus rates ranging from 0 to 40kg/ha. The study results revealed significant differences among treatments. Key growth parameters such as the plant height, number of leaves per plant, bulb diameter, sugar content, average bulb weight, and marketable yield were subjected to evaluation. The study result demonstrated that irrigation and phosphorus levels had a significant impact on onion growth and yield components. The highest marketable bulb yield of onion 28.08 tons/ha was obtained at 100% crop evapotranspiration (ETc) and 30 kg/ha of phosphorus application. The tallest plants (52.15 cm), maximum leaf numbers (14.55), and largest bulb diameter (6.28 cm). Moreover, this treatment yielded the highest average bulb weight (94.53) and marketable bulb yield (28.08 tons/ha). The study emphasized that adequate irrigation and phosphorus application positively impacted vegetative growth, bulb development, and overall onion yield. Water productivity analyses indicated the highest **water** productivity 10.38 kg/m^3 result was recorded from the treatment receiving 50% ETc and 20 kg/ha of phosphorus. Additionally, yield response factors indicated the sensitivity of onion yield to water deficit and phosphorus levels, emphasizing the importance of optimal irrigation and phosphorus management. Economic analysis results revealed the profitability of treatments involving 100% ETc with 30 kg/ha of phosphorus, demonstrating higher net benefits and substantial marginal rates of return (above 100%) compared to other treatments. Therefore, P rate of 30 kg ha^{-1} and irrigation level given at 100 and 75% ETc sounds good and can be recommended for onion production in the studied area.

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Determination of Irrigation Scheduling and Optimal Nitrogen Fertilizer Rate for Onion in Tiyo District, Arsi Zone, South Eastern Ethiopia

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Abstract:
The study was conducted at the Kulumsa Agricultural Research Center for three consecutive years. The objectives of this study were to determine optimum irrigation levels and nitrogen rates and investigate their interaction effect on the yield and quality of onion crops. The experiment was arranged in a Randomized Complete Block Design (RCBD) split plot with three replications. The experiment utilized three deficit irrigation levels (100%, 75%, and 50% ETc) were paired with five nitrogen rates ranging from 0 to 184 kg ha-1. The study result of onion bulb yield revealed significant differences at ($p<0.05$). The highest marketable bulb yield (28.66 tons ha-1) was found at 100% ETc and 138 kg ha-1 N fertilizer rate, whereas the lowest yield (16.84 tons ha-1) was found with 50% ETc and no N fertilizer. Water productivity (WP) varied significantly across treatments, with a maximum of 10.9 kg/m³ observed at 50% ETc and 138 kg ha-1 N fertilizer rate, while the minimum (4.42 kg/m³) was recorded at 100% ETc and no N fertilizer. This result highlights the significant interaction between N fertilizer and water levels for onion growth. Yield response factors (Ky) highlighted the sensitivity of onion crops to water deficit. The highest Ky (1.38) was observed at 75% ETc with no N fertilizer. Conversely, the lowest Ky values (0 and 0.26) were observed at 100% ETc with 138 kg ha-1 N and 75% ETc with 138 kg ha-1 N fertilizer rate, respectively. The economic analysis results showed that the treatments receiving nitrogen rates of 46, 92, and 138 kg ha-1 combined with all irrigation levels were significantly profitable. Consistently these treatments surpass a Marginal Rate of Return (MRR) of 100%. Therefore, a nitrogen rate of 138 kg ha-1 combined with irrigation levels of 100% and 75% ETc looks to be a good option for maximizing onion output; nevertheless, interactions of 46 and 92 kg ha-1 nitrogen with all irrigation levels are economically viable in the research area.

Keywords: Irrigation levels, nitrogen fertilizer rate, onion bulb yield, water productivity.

INTRODUCTION

The onion (*Allium Cepa* L.), which is grown in Ethiopia for its tasty leaves and aromatic bulbs, is regarded as one of the major horticulture crops in the world (Mubarak & Hamdan, 2018; Gebretsadik & Dechassa, 2018). Around 38,952.58 hectares were planted with onions in Ethiopia in 2020–2021, yielding 3,460,480.88 tons with an average yield of roughly 8.8 t ha^{-1} (CSA, 2021). This indicated that Ethiopia's onion production (8.8 t ha^{-1}) is far lower than the average for the world (18.8 t ha^{-1}). A lack of fertilizer, improper spacing, and difficulty obtaining high-quality planting materials coordinated with other cultural techniques can all limit onion production (CSA, 2021). During the "Meher" season, the crop is grown both with rain feeding and with irrigation. The off-season crop, grown with irrigation, makes up a large portion of the territory used for onion production in various parts of the nation. Even in regions where there has been growth, the productivity of onions is still far lower than in other African nations (Yitagesu et al, 2015).

Numerous recent studies have been conducted on the water and nitrogen fertilizer needs of onion crops, as well as the impacts of irrigation levels on yield and yield components, as stated in (Mubarak & and Hamdan, 2018). According to studies by Abdissa et al. (2011) and Tsegaye et al. (2016), a nitrogen fertilizer level of less than 100 kg ha^{-1} was shown to be enough for the production of onions. According to Russo's (2008) findings, the output of onions was not significantly affected by nitrogen fertilizer. Furthermore, it was shown that the onion crop responded to water deficit more moderately throughout the course of the growing season. As a result, it is preferable to divide the water stress across the growing season rather than waiting until the most crucial times for crop growth (Regulated Deficit Irrigation, or RDI) (Kirda, 2000; Kadayifciet al., 2005; Patel and Rajput, 2013). It was discovered that deficit irrigation, applied at various levels (up to 40%), was economically advised. It's possible that the different agro-pedo-climatic contexts of the places they analyzed contributed to the large variation in permissible deficit levels. Put another way, onions cultivated in various soil conditions and with varying crop management practices reacted differently to the application of N fertilizer and deficit irrigation.

As a result, among constantly shifting agro-pedo-climatic circumstances, choosing the ideal N-fertilizer rate and irrigation level is imperative for onion crops. Compared to many crops, onions, and other Alliums are more vulnerable to losing moisture and nutrients due to their shallow and unbranched root systems. Because of this, controlling soil moisture and nitrogen levels is essential to its production (Fitsum et al., 2015). Hence, they require and often respond well to additional fertilizers and supplemental irrigation. In the study area, irrigation is applied without considering the optimum crop water requirements, and the application of nitrogen is also based on the national recommendation which does not take cultivar and soil fertility and moisture regimes. As a result, inadequate management of irrigation water and fertilizer was considered to be an important limiting factor to onion production in the study area. The reasons behind the improper use of water and nitrogen fertilization are that sufficient information on the simultaneous application of water and nitrogen fertilization is not available in the study area. Following the existing problem, this study was conducted to determine the optimum rate of N and required irrigation level for major crops and identify the interactive effect of nutrient and moisture levels on yield and yield quality.

MATERIALS AND METHODS

Description of the Study Area

A field experiment was conducted for three consecutive years (2020/21 - 2022/23) at Kulumsa Agricultural Research Center (KARC). KARC is located in the Tiyo district of Arsi Zone, Oromia regional state, Southeastern Ethiopia (Figure 1).

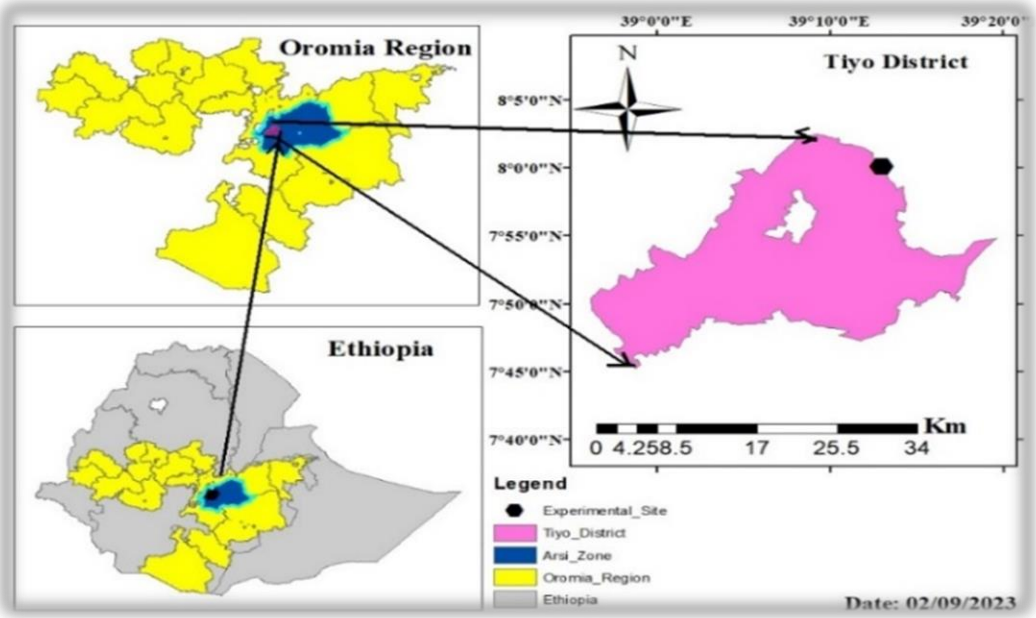

Figure 1: The map of the study area

The area receives an average annual rainfall of 821mm and has a uni-modal rainfall pattern. The peak season of the rainfall is from July to August. The average annual minimum and maximum temperatures are 9.9 and 23.1°C, respectively. The soil type is Luvisol/eutricnitosols with a good drainage system (Tafesse, 2003). The coldest month is December whereas March is the hottest month. The experimental site is located 08°00'855" latitude and 039°09'237" longitude and situated at an altitude of 2192 m asl. Effective rainfall and potential evapotranspiration of the cropping season at the study area is shown in figure (2).

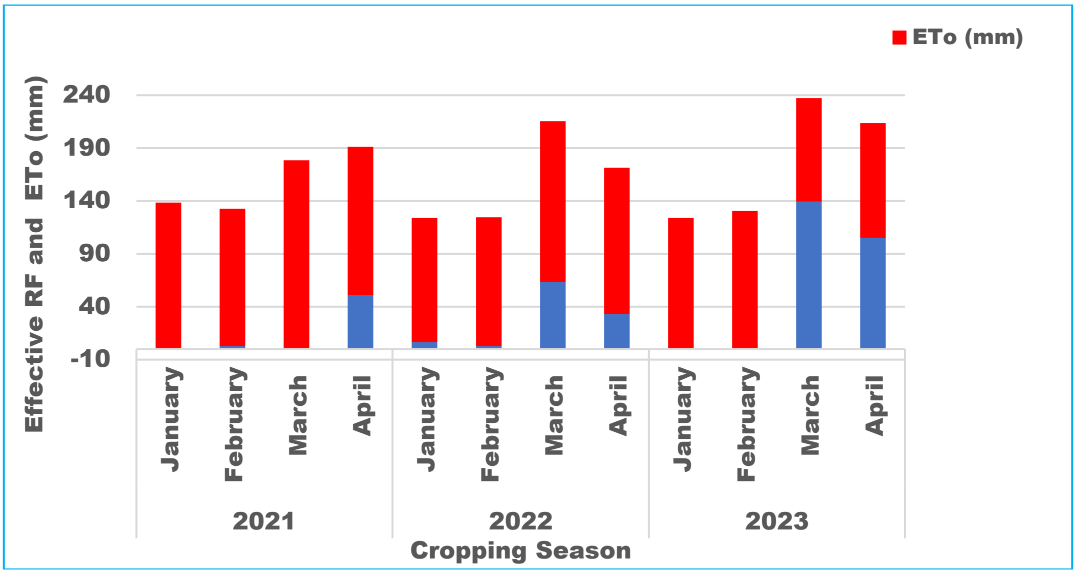

Figure 2: Effective rainfall and potential evapotranspiration of the cropping season

Experimental Design and Procedure

The experiment was laid out in RCBD split plot arrangement. The treatments were randomized both at the main and sub-plot levels and replicated three times. The deficit irrigation levels were in the main plot while nitrogen fertilizer rate treatments were assigned to the subplots.

Table 1: Description of treatment combination

Treatment	N rate (kg ha-1)				
Irrigation level	**0**	**46**	**92**	**138**	**184**
100% ETc	T1	T2	T3	T4	T5
75% ETc	T6	T7	T8	T9	T10
50% ETc	T11	T12	T13	T14	T15

Agronomic Data Collection

The seedlings of onions (*Bombay Red variety)* were raised following proper management practices as suggested by EARO (2004). Seedlings were hardened before transplanting to the main field to enable them to withstand the field conditions. The 45 days healthy and vigorous seedlings were transplanted. After transplanting, three full irrigations were applied uniformly to all plots with three days intervals, to ensure good plant establishment. Immediately after crop establishment, the irrigation was applied to individual plots according to the treatment requirement using a Parshall flume. Urea was used as a source of N; half of the N dose was applied at the time of transplanting and the remaining half was side-dressed after 45 days of transplanting. The P fertilizer was applied uniformly to all plots at the time of transplanting using triple superphosphate. The uniform field management was carried out on all plots as per the recommendations of EARO (2004). The experimental plots inter and intra-row spacing was done based on the recommended agronomic value for onion. Onion is planted on both sides of the ridge; so, transplanting was done on 40 cm, 20 cm, and 5 cm spacing of row plant (plant row spacing across furrow was 40 cm, across the ridge was 20 cm and along the ridge 5 cm between plants). The experimental field was divided into 45 plots and each plot size was 3mx3.5m dimension (10.5m^2) area to accommodate six furrows with a spacing of 60 cm and 3.5 m in length. Each plot consisted of five ridges and six furrows. A field channel was constructed for each block to irrigate the field. The amount of irrigation water applied was calculated using CROPWAT 8.0 software by using necessary input data of crop, soil, and climatic data. Irrigation water is applied up to field capacity by monitoring soil moisture content using the daily weather data. Soil moisture was measured before and after irrigation using the gravimetric method. Representative soil samples were taken from the experimental site for chemical analysis (PH, EC, CEC, total available N, OC, and OM) and physical properties (BD, Texture, FC, and PWP).

Yield and Yield Component of Onion:

The height of five randomly selected plants was measured from the ground level to the tip of the longest matured leaf at physiological maturity. The average number of leaves was counted from five randomly selected plants at physiological maturity. In each treatment, bulb diameter was measured at the physiological maturity stage of plants. The total soluble solids were measured from randomly selected bulbs of onion were squeezed into juices and the refractometer reading was recorded after the juices were dropped into the refractometer. The total soluble solid content is expressed in °Brix. The average weight was recorded using a digital balance and a means was reported. Marketable bulb yield was determined by recording the weights of bulbs that are free of mechanical damage, disease and insect pests, and medium to large (20-160 g) from the three central rows and converted into t/ha.

Determination of Crop Water Requirement

Crop water requirement (ETc):

Crop water requirement (ETc) was calculated from climatic data by directly integrating the effect of crop characteristics into reference crop evapotranspiration. FAO Penman-Monteith method was used for determining reference crop evapotranspiration (ET_o). The ratio of ET_c and ET_o, called crop coefficients (K_c), was used to relate ET_c to ET_o by the equation:

$$ETc = ETo * Kc \quad (1)$$

Where, ET_c = crop evapotranspiration (mm/day), ET_o = reference crop evapotranspiration (mm/day) and K_c = crop coefficient.

Irrigation Requirement (IR) was calculated by the following equation:

$$IR = CWR - \text{Effective rainfall} \quad (2)$$

Where, IR in mm, CWR in mm, and effective rainfall which is part of the rainfall that entered into the soil and made available for crop production in mm.

The irrigation schedule was worked out using Cropwat 8.0 software. In the model, one of the computation methods for the optimal irrigation scheduling for no yield reduction is the irrigation given at 100% readily available soil moisture depletion to refill the soil to its field capacity. The readily available water (RAW) was computed by the following formula:

$$RAW = P * TAW \quad (3)$$

Where, RAW is in mm, P is in fraction for allowable soil moisture depletion for no stress, and TAW is total available water in mm.

The total available soil Water (TAW) was computed from the soil moisture content at field capacity (FC) and permanent wilting point (PWP) using the following expression:

$$TAW = \frac{FC\text{-}PWP}{100\rho} * (Bd * Dz) \quad (4)$$

Where, FC and PWP are soil moisture content at field capacity in (%) on a weight basis, Bd is the bulk density of the soil in gm/cm^3, p *is* density of the water in gm/cm^3 and Dz is the maximum effective root zone depth in mm.

Soil bulk density was determined by taking undisturbed soil samples from an effective root zone at 20 cm intervals using a core sampler. The soil samples were oven-dried for 24 hours at a temperature of 105°C. Then, bulk density (ρb) was determined as (equation 5):

$$Bd = \frac{Ms}{Vs} \quad (5)$$

Where, Bd = Soil bulk density (g/cm^3), Ms = the mass of soil after oven-dry (g) and Vs = bulk volume of soil (cm^3).

The gross irrigation requirement, IRg, in a particular event, was computed from the expression:

$$IRg = \frac{CWR}{Ea} \quad (6)$$

Where, IRg is the gross irrigation requirement in mm, CWR is crop water requirement (mm/day) and Ea is the irrigation water application efficiency in fraction.

Water Productivity

Water productivity was estimated as a ratio of bulb yield to the total ET_c through the growing season and calculated using the following equation (8).

$$WP = (Y/ET) \tag{8}$$

Where WP is water productivity (kg/m^3), Y crop yield (kg ha-1) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

The yield response factor (Ky) was estimated from the relationship equation (9).

$$\left[1 - \left(\frac{Ya}{Ym}\right)\right] = Ky\left[1 - \left(\frac{ETa}{ETm}\right)\right] \tag{9}$$

Where, Ya=Actual harvested yield, Ym=Maximum harvested yield, Ky=Yield response factor, ETa=Actual evapotranspiration and ETm=Maximum evapotranspiration

The Ky values are crop specific and vary over the growing season according to growth stages with: Ky>1: crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced because of stress. Ky<1 the crop is more tolerant to water deficit and recovers partially from stress exhibiting less than proportional reductions in yield with reduced water use. Ky=1: yield reduction is directly proportional to reduced water use.

Statistical Data Analysis

Yield and yield components data and water productivity data were subjected to statistical analysis using the R-Software package. Means separation was carried out using the least significance difference (LSD) test at a 5% probability level.

Partial Budget Analysis

Economic analysis was conducted to evaluate the comparative advantages of irrigating level and nitrogen fertilizer rate interaction for onion production following the procedure of partial budget analysis set by CIMMYT (1988). The cost that varied during the period of this study was the expense incurred for labor to irrigate experimental plots and cost of fertilizer. The other costs are considered fixed since they hold similar among the experimental treatments. The value of variable cost (VC) was calculated based on the farm gate price of labor. The gross field benefit (GFB) was calculated by multiplying the selling price of the bulb yield of onion. The net benefit (NB) was calculated by subtracting the VC from GFB. The marginal rate of return (MRR) was calculated as the ratio of marginal NB and marginal VC of onion production. The bulb yield of onion was adjusted downwards by 10% before calculation to represent the actual yield that can be attained based on the farmers' practices. The treatments were listed in increasing order of VC. One treatment was discarded from further consideration through dominance analysis due to the greater variable cost, but lower net benefit. The marginal rate of return (MRR) was calculated for the remaining treatments. The acceptable MRR considered declaring profitability in this study was greater than or equal to 100%.

RESULT AND DISCUSSION

Soil Physical and Chemical Properties of the Experimental Site

Some selected soil physical and chemical properties of the experimental site are presented in Table 2. Percent of particle size determination revealed that the soil texture of the study area was sandy clay loam. The mean bulk density of soil in the study area was 1.25g/cm^3. The pH was computed by Potentiometry (1:2.5 soil: water ratio), where total nitrogen was calculated by Kjeldahl method, OC and OM were analyzed by Walkley and Black while available phosphorus was analyzed by Bray-II method. The mean pH, TN, OC, OM and Available P of the soil of the study area were 6.11, 0.12%, 2.16% and 3.72% and 19.76 mg/kg, respectively. The moisture content at field capacity, permanent wilting point and total available water were 33.6, 21.8%, and 11.8% respectively.

Table 2: Selected soils physicochemical properties status of experimental sites of Kulumsa

Physical properties							
BD (g/cm^3)	**Texture**			**Soil type**	**FC (%)**	**PWP (%)**	**TAW**
1.25	**Sand**	**Silt**	**Clay**	Sandy clay loam	33.60	21,8	11.8
	52	27	21				
Chemical properties							
pH	**TN (%)**	**OC (%)**		**OM (%)**		**Av. P (mg/Kg)**	
6.11	0.12	2.16		3.72		19.76	

Yield and Yield Component of Onion

Plant Height, Leaves Number, Bulb Diameter, and TSS:

The interaction of different irrigation levels and N-fertilizer rates had a significant impact on plant height. Specifically, the highest plant height of 55.16 cm was observed when the onion crop was subjected to 100% ETc with 184 Kg ha^{-1} N-fertilizer, which was statistically different from all other treatments except for 100% ETc with 138 Kg ha-1 N-fertilizer and 75% ETc with 184 Kg ha^{-1} N-fertilizer. Conversely, the shortest mean plant height of 40.76 cm was recorded when the onion crop was imposed to 50% ETc with 0 Kg ha^{-1} N fertilizer and was statistically inferior than all other treatments. The optimal performance of this growth parameter may be attributed to the fact that larger irrigation levels and fertilizer rates lead to an optimum soil water air balance around the plant root zone and the availability of sufficient soil nutrients. As Doorenbos and Pruitt (1977) noted, water is crucial for maintaining the turgid pressure of plant cells, which is essential for growth. On the other hand, low soil moisture stress may cause the closure of stomata to conserve soil moisture, leading to reduced CO_2 and nutrient uptake and hindered photosynthesis and biochemical reactions, ultimately affecting plant growth (Vaux and Pruit, 1983). This finding is in line with the results reported by El-Noemani et al. (2009), who found that soil water supply directly affects plant height growth, and that nitrogen enhances and extends plant vegetative growth (Ambomsa et al., 2023). Additionally, Tadesse et al. (2022) found that plant height increases with irrigation level and N rates.

Analysis of a\variance revealed that the combined application of irrigation levels and nitrogen fertilizer rates had a significant effect on the number of leaves in onion (Table 3). The number of leaves per plant (12.3) significantly improved with the treatment combinations of 100% ETc with 184 kg N ha^{-1} and 75% ETc fertilized with 184 kg N ha^{-1}. In the 100% ETc treatment, increasing the N levels to 184 kg N ha^{-1} resulted in a significant increase in leaf number per plant. The lowest mean number of leaves per plant (6.53) was recorded under the treatment 50% ETc with 0 Kg ha^{-1}N fertilizer and statistically different from all treatments except 50% ETc with 46 Kg ha^{-1} N-fertilizer, 75% ETc with 0 Kg ha^{-1} N-fertilizer and 100% ETc with 0 Kg ha^{-1} N-fertilizer. The maximum bulb diameter (6.11 cm) was recorded from 100% ETc and 138 kg ha^{-1} N fertilizer rate. The lowest (3.82 cm) bulb diameter was recorded with 50%ETc of irrigation level and no N application (Table 3). With an increase in the level of N from 0 to 138 kg ha^{-1}, the bulb diameter of onions increased. The increase in bulb diameter due to an increase in N could be due to the contribution of N to dry matter production and bulb diameter. The present result is in line with the findings of Tekeste et al. (2018), who found a 25% difference in bulb diameter due to the application of 138 kg ha^{-1} N compared with the control treatment. Nasreen et al. 2007 and Guesh (2015) also reported significantly higher bulb diameter due to the application of 120 kg ha^{-1} N. The effects of irrigation level and N rate on TSS were significant ($p<0.05$), as shown in Table 3. The highest (12.30 °Brix) TSS was recorded in the experimental plot treated with 100% ETc and 184 kg ha^{-1} N fertilizer. The lowest (6.53 °Brix) TSS was obtained from the application of 50% ETc with 0 kg ha^{-1} N-fertilizer rates. When the Irrigation level was kept constant, TSS also increased as the N rate increased.

Table 3: Results of irrigation and nitrogen levels on plant height, leaves number, bulb diameter, and TSS

Treatments	**Plant Height (cm)**	**Leaves Number**	**Bulb diameters (cm)**	**TSS (^{Brix})**
100% ETC*0 N	46.10^{fg}	6.87^{fg}	4.64^{hfg}	7.60^{fg}
100% ETC*46 N	48.34^{ef}	8.61^{fegd}	5.53^{bc}	8.61^{def}
100% ETC*92 N	51.32^{cd}	9.8^{fbecd}	5.69^{ba}	9.80^{cd}
100% ETC*138 N	53.72^{ab}	11.31^{ba}	6.11^{a}	11.31^{ab}
100% ETC* 184N	55.16^{a}	12.30^{a}	4.95^{def}	12.30^{a}
75% ETC*0 N	43.31^{h}	7.6^{fg}	4.29^{h}	6.87^{g}
75% ETC*46 N	46.97^{gf}	8.4^{fed}	4.69^{hfg}	8.40^{e}f
75% ETC*92 N	49.85^{cde}	9.77^{fbecd}	5.23^{ecd}	9.77cd
75% ETC*138 N	52.09^{bc}	10.40^{bc}	5.32^{bcd}	10.40^{bc}
75% ETC* 184N	53.81^{ba}	12.22^{a}	5.23^{ecd}	12.22^{a}
50% ETC*0 N	40.76^{i}	6.53g	3.82^{i}	6.53^{g}
50% ETC*46 N	44.80^{gh}	8.27^{feg}	4.47^{hg}	8.26^{ef}
50% ETC*92 N	47.66^{ef}	9.47^{fecd}	4.84^{ef}	9.47^{cde}
50% ETC*138 N	49.39^{de}	10.13^{bcd}	5.16^{ecd}	10.13^{bc}
50% ETC* 184N	51.08^{cd}	9.97^{becd}	5.24^{ecd}	9.97^{c}
LSD (0.05)	**1.06**	**1.23**	**0.30**	**1.23**
CV (%)	**1.29**	**19.43**	**3.58**	**19.43**

This means values in columns and rows followed by the same letter are not significantly different at $P< 0.05$, LSD = least significant difference; and CV= coefficient of variation in percent.

Average Bulb Weight and Bulb Yield

The interaction effect of irrigation level and N rate on the average weight of onion bulbs was significant ($p<0.05$) (Table 4). The average bulb weight of onion initially increased with increasing irrigation levels and nitrogen rates, but declined at higher levels of irrigation and N rates. However, both the magnitude and pattern of increase or decrease were not the same at all N and irrigation levels. Thus, at 46 kg N ha^{-1}, increasing irrigation levels from 50 to 100% ETc increased the mean bulb weight of onion by 19 and 49%, but further increase had no significant effect. Similarly, at 75% ETc, increasing the N rate from 0 to 138 kg N ha^{-1} increased the mean bulb weight by 48 and 25%, while a further increase in N had no significant effect. Similar results were observed for other irrigation levels and N rates. The interaction results showed that the bulb yield of onions was determined by both N rates and irrigation levels. Bulb weight increased with increasing N levels, reaching a maximum at higher N rates in combination with increasing reduced water stress levels. These results were similar to those reported by Worojie et al. (2016). The combined effect of different irrigation levels and N-fertilizer rates showed a significant effect on onion marketable bulb yield. The maximum marketable bulb yield of (28.66 ton/ha) was obtained from 100% ETc with 138 Kg ha^{-1} N-fertilizer, and it was statistically different from all treatments. The lowest marketable bulb yield (16.84 t/ha) was recorded from 50% ETc with 0 Kg ha^{-1} N-fertilizer, which was significantly different from all other treatments. The study results showed that there was an increasing trend in bulb yield with an increase in irrigation level and N fertilizer rate to 138 kg ha^{-1} then it started to decrease. The highest bulb yield obtained with higher irrigation levels was due to the better performance of the growth parameters. The highest level of irrigation and fertilizer rate ensures the optimum growth of the crop by ensuring a balanced water and nutrient supply.

Higher nitrogen and irrigation levels help in the plant's vegetative growth, which enhances the average assimilate accessible for storage and increases the average bulb weight, both of which provide an advantage to raising the marketable bulb yield (Gebregwergis et al., 2016). According to James (2014), when irrigation levels were higher (100 and 120% ETc), the improvement in marketable bulb yield that resulted from increasing the N rate was generally greater than when there was a water scarcity. The increase in vegetative growth and increased assimilate production, which is linked to an increase in leaf area index, bulb diameter, and average bulb weight, may be responsible for the increase in marketable bulb yield caused by the application of nitrogen and irrigation water (Neeraja et al., 1999). This result is consistent with the findings of Bagali et al. (2016) and Quadir et al. (2005). Additionally, Satyendra et al. (2007) found that as irrigation levels rose, bulb output dramatically increased.

Table 4: Results of Irrigation and nitrogen levels on average bulb weight, marketable bulb yield

Treatments	**Average bulb weight (gm)**	**Marketable bulb yield (ton/ha)**
100% ETC*0 N	67.90^{e}	19.48^{g}
100% ETC*46 N	78.24^{cd}	23.79^{de}
100% ETC*92 N	85.5^{bc}	26.85^{b}
100% ETC*138 N	99.17^{a}	28.66^{a}
100% ETC* 184N	93.61^{a}	27.32^{b}
75% ETC*0 N	62.55^{e}	18.76^{gh}
75% ETC*46 N	71.53^{de}	21.57^{f}
75% ETC*92 N	80.40^{cd}	24.67^{cd}
75% ETC*138 N	92.71^{ba}	26.80^{b}
75% ETC* 184N	90.66^{ab}	25.37^{c}
50% ETC*0 N	52.08^{f}	16.84^{i}
50% ETC*46 N	65.16^{e}	18.36^{h}
50% ETC*92 N	77.87^{cd}	21.72^{f}
50% ETC*138 N	93.30^{ab}	24.10^{de}
50% ETC* 184N	91.50^{ab}	23.41^{e}
LSD (0.05)	**9.11**	**1.07**
CV (%)	**7.09**	**2.74**

This means values in columns and rows followed by the same letter are not significantly different at $P< 0.05$, LSD = least significant difference; CV coefficient of variation in percent.

Crop Water Requirements, Water Productivity and Yield Response Factor

Crop Water Requirement (CWR):

The seasonal precipitation during the aforementioned period in the experimental area is very low. Hence, it demands the application of irrigation water for crop production to be conducted since the precipitation could not satisfy the onion crop water requirement. Crop water required was calculated using CROPWAT 8 and the computed irrigation amount was applied to meet crop water requirements under the dry conditions. During the growing season 441mm, 331, and 220mm for 100%ETc, 75%ETc, and 50%ETc, crop evapotranspiration (ETc) was applied respectively. It is very important to notice that about 25% and 50% of ETc was saved when 75% and 50%Etc of water were applied in comparison with optimal irrigation treatment (100% ETc). This result is in agreement with the findings of Igbadun et al. (2012) who showed that the water needs of onion crops reduced by about 20% with an increase in irrigation deficit of 50% of reference evapotranspiration.

Water Productivity (WP):

The interaction effect between irrigation levels and N fertilizer rate treatments had a significant ($P \leq 0.05$) influence on the water productivity of onions (Table 5). Both irrigation and N application had a positive effect on the total bulb yield. Water productivity, however, decreased with increasing irrigation depth, whereas N application significantly increased water productivity at all irrigation levels (Table 5). The maximum water productivity (10.9kg/m^3) of onion was observed at 50% ETC*138 N ha^{-1} and on the contrary the minimum water productivity (4.42kg/m^3) was recorded at 100% ETC*0 N treatment. This shows that the interaction of N fertilizer and water amount is significant for the growth of onion crops. The study result shows that at the same amount of irrigation level of 50% ETc, increasing the fertilizer rate from 46 to 138 kg N/ha increases the water productivity of onion from 8.32 to 10.9 kg/m^3 and decreases the relative yield reduction of onion by 20.3%. Similar results were observed for the other irrigation and N combinations. In the current study, it was observed that the water productivity of onion plants was influenced by both irrigation levels and nitrogen rate. The results of the present study are in agreement with the findings of Tayel et al. (2010), who reported maximum water productivity of garlic plants under an N-irrigation combination of 50% ETc + 285 kg N ha-1. These results are also in close agreement with Kebede (2003) and Samson and Ketema (2007), who reported that when irrigation water becomes a limiting factor, yield losses due to reduced soil moisture can be compensated for by water use efficiency.

Yield Response Factor (Ky):

The observed yield response factors (Ky) result of onion for irrigation and N fertilizer level ranged between 0.00 and 1.38. The magnitude of the Ky value indicates the sensitivity of the irrigation protocol for water deficit and subsequent yield decrease. According to Kirda, et al. (2000) the Ky value for field crops goes from 0.2 to 1.15 which agrees with the reported result by Watkinson (2008). From the study result of Table 5 the highest Ky was 1.38 attained at the treatment 75% ETC*0 N of irrigating 75%ETc without N fertilizer. The higher Ky values could be an indication of the severity of water deficit and fertilizer rate at onion bulb yield. The lowest result of yield response factors of 0 and 0.26 was observed at the treatment receiving 100%ETc*138N/ha followed by 75% ETC*138 N, respectively. This demonstrated the optimal response of water and fertilizer amount on onion yield. This means that the rate of relative yield decline caused by water reduction is proportionally smaller than the rate of relative evapotranspiration deficit. According to the results of Table 5, a moisture deficit of more than 25% combined with a fertilizer rate of less than 92kg ha-1 N results in a yield reduction of 24.74 to 34.54%. (Table 5).

Table 5: Crop and irrigation water requirement, water productivity and yield response factor

Treatments	Bulb Yield (kg ha-1)	CWR (mm)	WP (Kg/m^3)	Relative water saved (%)	Relative yield reduction (%)	Ky
100% ETC*0 N	19,480	441.6	4.42^{i}	-	32.03	-
100% ETC*46 N	23,790	441.6	5.40^{gh}	-	16.99	-
100% ETC*92 N	26,850	441.6	6.09^{g}	-	6.32	-
100% ETC*138 N	28,660	441.6	6.50^{ef}	-	-	-
100% ETC*184N	27,320	441.6	6.20^{fg}	-	4.68	-
75% ETC*0 N	18,760	331.2	5.66^{h}	25	34.54	1.38
75% ETC*46 N	21,570	331.2	6.51^{e}	25	24.74	0.99
75% ETC*92 N	24,670	331.2	7.45^{cd}	25	13.92	0.56
75% ETC*138 N	26,800	331.2	8.08^{b}	25	6.49	0.26
75% ETC*184N	25,370	331.2	7.66^{c}	25	11.48	0.46
50% ETC*0 N	16,840	220.8	7.63^{e}	50	41.24	0.82
50% ETC*46 N	18,360	220.8	8.32^{d}	50	35.94	0.72
50% ETC*92 N	21,720	220.8	9.84^{b}	50	24.21	0.48
50% ETC*138 N	24,100	220.8	10.91^{a}	50	15.91	0.32
50% ETC*184N	23,410	220.8	10.60^{a}	50	18.32	0.37

Partial Budget Analysis

The treatments receiving the fertilizer rate of 46, 92, and 138kg of N/ha at all levels of irrigation amount were found economically profitable (Table 6) because they gave Marginal Rate of Return (MRR) over 100%. On the other hand, the treatments receiving the fertilizer rate of 0 and 184kg N at all levels of irrigation amount were economically dominated (Table 6) because they gave less than 100%MRR. The maximum benefit of 33.51 birr for every birr investment in labor and fertilizer was attained from the application of 138kg N/ha fertilizer at 100%ETc followed by 50% ETc with fertilizer amount of 92 kg N/ha, which gave 33.00 birr return for every birr investment (Table 6). Irrigating the optimum amount of irrigation water with the application of 46kg ha-1 of N also provided an equivalent economic return of 32.49 birr for every birr investment (Table 6).

Table 6: Partial budget analysis based on mean values for onion production using different levels of N fertilizer and irrigation amount at Kulumsa

Treatment	Bulb yield (kg ha-1)	Total Variable Cost (ETB/ha)	Net Return (ETB/ha)	MRR (%)
100% ETC*0 N	19,480	6,400	821,500	-
100% ETC*46 N	22,790	10,600	957,975	3249
100% ETC*92 N	25,250	14,800	1,058,325	2389
100% ETC*138 N	28,660	19,000	1,199,050	3351
100% ETC*184N	27,320	23,200	1,137,900	D
75% ETC*0 N	18,760	4,800	792,500	-
75% ETC*46 N	21,570	9,000	907,725	2743
75% ETC*92 N	24,670	13,200	1,035,275	3037
75% ETC*138 N	26,800	17,400	1,121,600	2055
75% ETC* 184N	25,370	21,600	1,056,625	D
50% ETC*0 N	16,840	3,200	712,500	-
50% ETC*46 N	18,360	7,400	772,900	1438
50% ETC*92 N	21,720	11,600	911,500	3300
50% ETC*138 N	24,100	15,800	1,008,450	2308
50% ETC* 184N	23,410	20,000	974,925	D

CONCLUSION

The study was conducted at Kulumsa Agricultural Research Center for three consecutive years and aimed to determine the optimum irrigation level and fertilizer rate for onion yield and quality. The experiment assessed three irrigation levels (100%, 75%, and 50% ETc) and five nitrogen rates ranging from (0 to 184 kg ha^{-1}) using a split-plot Randomized Complete Block Design with three replications. The study found that 100% ETc with 138 kg ha^{-1} N fertilizer contributed to the highest yield of 28.66 tons/ha, while 50% ETc with 0 kg ha^{-1} N resulted in the lowest yield of 16.84 tons/ha. The interaction between nitrogen fertilizer and irrigation levels significantly affected onion growth. Water productivity varied widely, with the lowest at 100% ETc with 0 kg ha^{-1} N (4.42 kg/m^3) and the highest at 50% ETc with 138 kg ha^{-1} N (10.9 kg/m^3). The yield response factor highlighted onion's sensitivity to different irrigation and fertilizer rates, with severe impacts observed at 75% ETc with 0 kg ha^{-1} N (Ky of 1.38) and optimal responses at 100% ETc with 138 kg ha^{-1} N (Ky of 0) and 75% ETc with 138 kg ha^{-1} N (Ky of 0.26). Economically, nitrogen rates between 46 and 138 kg ha-1 were profitable across all irrigation levels. Notably, combinations of 138 kg ha-1 nitrogen with 100% or 75% ETc showed the highest Marginal Rates of Return (MRR), making them advisable for maximizing onion yield under irrigated conditions.

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Climate Change Impacts on Livestock Production and Adaptation Strategy used by Households in Loka Abaya District, Southern Ethiopia

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Abstract:
Climate change has affected the livelihoods of many households in many developing countries. The current study assessed the impacts of climate change on livestock production and the adaptation strategies used by households. A multistage sampling strategy was used to study select areas. In the first stage, four Kebele (lowest administration unit), two representing Moist-Weina Dega and other two representing Moist-Kolla were purposefully selected based on agroecological conditions and information indicating the involvement of different intervention works. A total of 160 households (73 from Moist-Weina Dega and 87% from Moist-Kolla) were selected using proportionally sampling strategy. About 6 – 8 focused group discussants were involved to complement household interviews. The finding revealed that households observed shifts in climatic indicators such as temperature, rainfall distribution/amount, and the occurrence of extreme events. Nearly 90% of households observed an increasing temperature trend, which was more commonly observed in moist Kolla (95%) than in moist Weina Dega (80%). About 61% and 76% of households perceived a decline in rainfall amount and a change in seasonal distribution, respectively, where it was more pronounced in the moist Kolla area than the moist Weina Dega area, which greatly affected crop and livestock production. Feed shortages and quality deterioration, reduced water availability, higher heat stress, and increased disease frequency were direct effects of climate change on livestock production, which ultimately reduced animals' weight gain, reduced milk yield and increased livestock mortality. Collecting and storing rainwater, income diversification, livestock destocking and shifting from large ruminants to small ruminants (goats), and livestock feed storage and temporary migration were livestock production-related adaptation strategies used by households. The use of improved livestock breeds (goats and poultry) and the supply of modern bee hives were reported as some of the introduced technologies in the livestock sector aimed at enhancing the adaptive capacity of households to climate change. The present study concluded that climate change greatly affected livestock production and the livelihood of producers and that there should be interventions supporting the adaptive capacity of households.

Keywords: Agro ecology, Adaptation strategy, Climate change, Livestock production

INTRODUCTION

Nowadays, the world is facing climate change, which is the most significant environmental challenge and has very considerable implications for various sectors, including agriculture in general and livestock production in particular (Sejian et al., 2015a). Globally, households experienced climate change mainly due to temperature and unpredictable rainfall distribution, ultimately affecting agricultural production (Karki et al., 2020). Livestock production has remained a major source of income and livelihood base for many households in most developing countries (Herrero et al., 2016). In Ethiopia, livestock production accounts for roughly 40% of the agricultural GDP. The rapidly increasing demand for animal-derived food suggests the importance of increasing livestock productivity. While Ethiopia has a large livestock population, the sector's productivity has remained very low due to many challenging conditions. Livestock production is highly vulnerable to the impacts of climate change due to the sector's dependence on natural resources and the susceptibility of animals to extreme weather events (Weindl et al., 2015). Seasonal fluctuations in herbage quality and quantity associated with climate change and variability have significant impacts on livestock production and lead to a decline in livestock productivity and production efficiency (Sejian, 2013). Further, many households in Ethiopia and other sub-Saharan Africa are still dependent on agriculture for their economies, where it provides food, income, and employment for the predominantly for many rural populations (Gemeda and Sima, 2015). Most interestingly, several million people in these areas are living and located in areas prone to extreme drought events leading to food insecurity and water shortages (Bekwet et al., 2015). The Loka Abaya district in southern Ethiopia is the place that has been deeply affected by climate change. In the area, households heavily rely on livestock production as a crucial source of income and livelihood for their residents. However, rising temperatures, irregular rainfall patterns, prolonged droughts, and other climate-related disturbances have resulted in significant disruptions to traditional livestock farming practices and the overall well-being of local communities. Considering these background pieces of information, the current research article was aimed at providing a comprehensive analysis of climate change impacts on livestock production and exploring the adaptive strategies employed by households as important intervention options to mitigate the impacts of climate change. This study also aimed to examine specific local contexts by exploring farmers' practices to contribute valuable insights to inform future interventions and aid in the development of effective adaptation strategies.

MATERIAL AND METHODS

Description of Study Area

The research was conducted in Loka Abaya, located in Sidama regional. Loka Abaya is one of the districts in the Sidama Region of Ethiopia. The district is surrounded by the Oromia Region to the south, Lake Abaya to the southwest, the Wolaita Zone to the west, Boricha to the north, Dale to the northeast, Shebedino to the east, and Aleta Chuko to the southeast. It is located 50 km from Hawassa, a regional city, and 320 km from Addis Ababa, the capital city. The district is located at 6°40' 05''-6°54' 06''N and 38 0 00'13''-38 015'00''E with an altitudinal range of 560 to 1700 masl. The district's annual temperatures ranged between 17 and 20 °C, with an average annual rainfall of 900 to 1400 mm (Bekwet et al., 2015). Moist Kolla and Moist Weina Dega traditional agroecological conditions recognized in the district (Bekwet et al., 2015) fall under two seasons called Belg (February to April) and Kermit (July to October). High temperatures and the erratic nature of rainfall are common climatic problems in the study district. Natural resource degradation, frequent droughts resulting from climate change/variability, and increasing human population were major agriculture and food security-related problems (Bekwet et al., 2015). Mostly Kolla and Moist Weina Dega were traditionally recognized agro-ecological conditions in the districts. Mixed crop-livestock production with varied degrees across the district is practiced.

Sampling Strategy and Sample Size

A multistage sampling strategy was employed to select the study area. In the first stage, Kebeles in the Loka Abaya district were stratified based on traditional agroecological classification. Traditionally, there are agro-ecologies named Moist Weina Dega and Moist Kolla. A total of four Kebeles representing the aforementioned agro ecology were purposefully selected to carry out the study. Accordingly, Desse and Diremanchu represented Moist Weina Dega, whereas Argada Haro Dintu and Danshe Gambella were selected from the Moist Kolla area. The Kebeles were selected based on information that there have been interventions enhancing the community's capacity for better income. A total of 160 households, including 73 representing Moist Weina Dega and 87 representing Moist Kolla, were selected using a proportional and random sampling strategy. The proportional sampling strategy was employed to determine sample size per agro ecology, and the random sampling strategy was employed to include households for interviews.

Data Collection and Data Type

Household interviews and focused group discussions (FGDs) were used to obtain primary data. Semi-structured questionnaires that were pre-tested before the actual survey were used to interview households at their farm gates. Enumerators were trained to carry out household interviews with questionnaires that were translated into a local language that the community understands well. FGDs were employed to support the household interviews. Focused group discussants were selected based on their experience/knowledge of their environment, age, and active participation in community activities. They were elderly people, farmers with long farm experiences and the ability to use different options to mitigate climate change and related extreme events.

Data Analysis and Statistical Methods

Qualitative data obtained from survey, focused group discussion and physical observation was organized, summarized and interpreted through concept and opinions. To describe the explanatory variables collected on farmer's perception about climate change and others variables (temperature and rainfall data), descriptive statistics such as mean, frequency and percentage were computed independently for each parameter involved. Analytical tool of Statistical Package for Social Science (SPSS) version 20 was used for data analysis. Index method of ranking also used for ranking of parameter such as challenges affecting adaptive capacity of farmers and others similar parameters. Chi-square (X^2) test was employed to know the significant dependence of parameters between agro ecologies.

RESULT AND DISCUSSION

Demographic and Socio-Economic Characteristics of Respondents

The majority (85%) of the interviewed households, 87% in Moist Weina Dega and 83% in Moist Kolla, were male (Table 1). The result was consistent with previous studies (Gemiyu, 2009; Kashay et al., 2019; Addis and Abirdew, 2021). The overall mean age of interviewed households was 42.4 years. Households in Moist Kolla were significantly ($p<0.05$) older than those in Moist Weina Dega. Households in the present study were younger compared with a previous report (Tesfaye, 2008; Kashay et al., 2019), who reported a mean age of 52 years. The age of the household would be associated with their ability to better understand the changes that happened in the environment. This was consistent with previous studies (Kashay et al., 2019; Deressa et al., 2009), which reported age as a proxy measure of farming experience, indicating farmers with longer farming experience are more likely to perceive climate change and its impacts. Nearly 80% of households in the two studied agro ecologies were literate, with the majority (61.67%) attaining elementary school, followed by those reaching secondary school. Nearly 97% of sampled households were married, with 0.6% and 2.5%, respectively, being divorced and widowed. It was mentioned during the survey that being widowed would make households more vulnerable to disasters, including climate change impacts, as husbands play a higher role in income-generating activities. The mean family size of 4.98+1.18 was significantly ($p<0.05$) different between Moist

Weina Dega and Moist Kola. A higher mean number of households per family in Most Weina Dega (5.54+1.1) agro ecology would be associated with a relatively more conducive area for crop production than in Moist Kola. The result was in agreement with a previous study (Assefa, 2007), which reported a higher mean family size in Moist Weina Dega (7.9) than in Moist Kola (6.8). Households in moist Weina Dega are more reluctant to move outside looking for feed, water, and water for livestock and humans, which is more frequent in moist Kola.

Table 1: Demographic and socio-economic characteristics of households in study area

Variables	MWD		MK		Overall		X^2	*p*-value
	N	%	N	%	N	%		
Sex								
Male	64	87.67	72	82.76	136	85		
Female	9	12.33	15	17.24	24	15		
Educational status							**2.5600**	**0.1138**
Had not attained school	18	24.66	20	22.99	38	21.11		
Elementary school	54	73.97	57	65.52	111	61.67		
Secondary School	16	21.92	6	6.90	22	12.22		
Degree/diploma	5	6.85	4	4.60	9	5.00		
Marital status							**133.7626**	**<0.0001**
Single	0	0	0	0	0	0		
Married	71	97.26	84	96.6	155	96.88		
Divorced	0	0	1	1.15	1	0.625		
Widowed	2	2.74	2	2.3	4	2.5		

MWD = Moist-Weina Dega, MK = Moist-Kolla. N = number of households.

Land Holding of Respondents

The mean age, land, and livestock holdings in the study area are given in Table 2. Overall, the mean land holding observed in the present study was 1.13 ha/HH, which was narrower than the corresponding mean of 1.52 ha reported by Endeshaw (2007), 1.5 ha in the Alaba area (Gemiyu, 2009), and 2.3 ha of total mean land holding in the Kowet district of the North Shewa zone. The mean land size recorded in Moist-Kola (1.20 ha/HH) was significantly ($p<0.05$) lower than the corresponding mean value in Moist Weina-Dega (1.04 ha/HH), which was attributed to the difference in population density.

Livestock Holding of Respondents

The mean and standard deviation of different livestock species owned by sampled households are presented in Table 2. Cattle were the dominant livestock species, with a mean of 4.2 heads, which was significantly ($p<0.05$) different between the Moist Weina Dega (3.2 heads) and the Moist Kola area (5.2 heads). More cattle holdings in Moist Kola indicate a higher dependency of households on livestock production, which may result from more grazing land owned by households. Goats with an overall mean of 6.95+1.86 were significantly ($p<0.05$) higher in moist Kola (8.91+2.4) than in moist Weina Dega (5.0+1.3). The higher goat holdings in Moist Kola indicated the preference of goats among households and the ability of goats to adapt under challenging conditions—their ability to utilize browse species that are rarely utilized by other livestock. The mean goat holding observed in the present study was higher compared with a previous study (Endeshaw, 2007), which reported a mean of 5.98 goats per household in the Loka Abaya area. Sheep keeping was less common, with an overall mean of 0.61 heads, and the result was not significantly ($p>0.05$) different between the two agro-ecological conditions. Donkeys were the other valuable livestock species in the study area, with an overall mean of 0.84 heads. Donkeys play a great role in transporting goods from market to market and vice versa. Households further mentioned that they rent donkeys to obtain cash income, which notably contributed much to fulfilling income gaps for families during adverse times. Poultry was also another livestock species kept by many households in the study area. The observed mean (4.8) of poultry ownership was significantly ($p<0.05$) different between the two agro ecologies, where a higher mean was observed in moist Weina-Dega than in moist Kola. This difference is mainly attributed to the difference in poultry feed availability and its adaptability.

Table 2: Mean ± Standard deviation of family size, land holding and livestock holding of households in Moist Weina Dega and Moist Kolla agro-ecology

Variables	Moist Weina Dega	Moist Kolla	Overall mean	Significance
Age (year)	39.8±4.8	44.9±5.9	42.4±5.3	*
Family size	5.54±1.1	4.43±0.9	4.98±1.18	*
Land size (ha)	1.04±0.26	1.20±0.56	1.13±0.38	*
Livestock species				
Cattle	3.20±1.3	5.20±1.5	4.2±1.4	*
Goat	5.0±1.3	8.91±2.4	6.95±1.8	*
Sheep	0.71±0.8	0.51±0.8	0.61±0.8	Ns
Donkey	0.85±0.6	0.83±0.8	0.84±0.7	Ns
Chicken	5.48±2.1	4.21±1.5	4.8±1.8	*
TLU	3.31	5.05	4.0	

*$p<0.05$, TLU: Tropical Livestock Unit with conversion factor of 0.7, 0.5, 0.1, 0.1 for cattle, donkey goat and sheep respectively (Jalanke, 1982) and TLU for poultry = 0.013 (Strock et al., 1991).

Community Perception of Climate Change

Table 3 presents the change in climatic indicators in the study area based on farmers' perceptions. The perception of farmers to climate change observed in the present study was based on how they perceive the changes in climatic indicators. About 60% of the sampled households in the study area-71% in Moist Kolla and 48% in Moist Weina Dega observed that the amount of rain received had decreased. The decrease in rainfall in the present study was consistent with a previous study (Kashay et al., 2019), which reported more than 90% of interviewed households perceived a decrease in rainfall amount in the semiarid region of eastern Tigray region of Ethiopia. Chi-square (X^2) indicated that the decrease in rainfall amount was differently ($p<0.001$) perceived between moist Weina Dega and moist Kolla agro ecology – where perception was more common in moist Kolla. Nearly two-thirds of the sampled households in the study area observed changes in the seasonal distribution and patterns of rainfall over years. They further mentioned that rain has not only been coming lately but had also stopped early. The delayed rainfall onset and early cessation have limited crop growing periods and reduced feed and water availability to humans and livestock. Almost 96% of households in Moist Kolla and 81% in Moist Weina Dega reported increased environmental temperatures, which had a significant impact on their livelihood. None of the households in Moist Kolla agroecology observed a decreasing trend for environmental temperature. The result was in agreement with a previous study reporting more than 85% of households observed increasing temperature trends in the semiarid area of the eastern Tigray region (Kashay et al., 2019). Addis and Abirdew (2021) also reported an increase in environmental temperature in the central part of Ethiopia. The increase in temperature was significantly ($p<0.001$) dependent on agro ecology where households in the Kolla area more commonly perceived the increase in temperature as compared with proportion of households who perceived in the moist Weina Dega area.

Increased incidences of drought were more significantly ($p<0.0001$, $X^2 = 77.2894$) increased in Most Kolla (89%) than in Moist Weina Dega (27%), which could be associated with low rainfall amounts and changed seasonal distribution in Moist Kolla. Sometimes, households interviewed experienced unexpected flooding resulting from high rainfall at certain points in time, which causes crop damage, soil erosion, and property destruction.

Table 3: Perception of households to climate change

Indicators	Moist Weina Dega		Moist Kola		Overall		X2	p-value
	N	%	N	%	N	%		
Rain fall amount							**51.8422**	**<0.0001**
Decreased	35	47.95	62	71.26	97	60.63		
Increased	14	19.18	2	2.30	16	10.00		
No change	16	21.92	16	18.39	32	20.00		
I don't know	8	10.96	7	8.05	15	9.38		
Rainfall seasonal distribution							**102.762**	**<0.0001**
Changed	43	58.90	78	89.66	121	75.63		
No change	13	17.81	0	0.00	13	8.13		
I don't know	17	23.29	9	10.34	26	16.25		
Temperature							**100.254**	**<0.0001**
Increased	59	80.82	83	95.40	142	88.75		
Decreased	2	2.74	0	0.00	2	1.25		
No change	3	4.11	0	0.00	3	1.88		
I don't know	9	12.33	4	4.60	13	8.13		
Drought incidence							**77.2894**	**<0.0001**
Increased	20	27.40	78	89.66	98	61.25		
Decreased	3	4.11	0	0.00	3	1.88		
I don't know	50	68.49	9	10.34	59	36.88		
Flood incidence							**36.5111**	**<0.0001**
Increased	32	43.84	38	43.68	70	43.75		
Decreased	15	20.55	36	41.38	51	31.88		
No change	12	16.44	7	8.05	19	11.88		
I don't know	14	19.18	6	6.90	20	12.50		

Climate Change Impacts on Livestock Production

All households interviewed in the study area believed climate change had significant impacts on livestock production. The impact of climate change on livestock production was identified through household interviews and FGDs and ranked in order of importance (Table 4). The result indicated feed and water resource shortage, increased heat stress, and causing mortality were observed as major direct impacts of climate change on livestock production both in moist Dega and Kolla areas. The results of household interviews and FGDs showed that climate change has affected livestock production through its effects on feed resources. Reduction in the quantity of feed resources, decline in quality, seasonal fluctuation, and poor palatability of grass were observed livestock feed resources related impacts of climate change. Households further mentioned that climate change-related feed resource shortages and quality declines were the most serious, mainly during dry seasons, indicating there were highly seasonal variations in feed resources. In agreement with the results of the current study, reducing feed resource availability and declining quality were reported as potential impacts of climate change on livestock production (Kassahun, 2016; Mulata, 2016). Aklilu et al. (2013) further reported that the spatial distribution and temporal availability of pasture and water are highly dependent on rainfall. The author further mentioned that changing temperature ranges will result in changes in feed and pasture availability and quality, as well as an increased incidence of disease and pests. Households further explained that feed resource availability and quality decline were highly associated with rainfall amount and seasonal distribution, were insufficient and irregular rainfall highly affected feed production and quality. In agreement with this, a previous study reported that climate change affected pasture and rangeland production, causing a change in the nutrient balance of feed (Izaurralde et al., 2011).

On the other side, households mentioned that higher temperatures, which are exacerbated by climate change, caused a decline in the nutrient content of feed, quality deterioration, and made already scarce feed resources less palatable for livestock consumption. In line with the observations of households in the present study, previous studies reported that an increase in temperature resulted in poor-quality feed resources through deteriorating nutrient compositions (Thornton, 2009; Izaurralde et al., 2011). Households also believed that climate change-imposed impacts on livestock production by affecting water resources such as decreasing the volume of drinking water and drying up rivers, wells, and wetlands. Previous findings also reported climate change increased water stress on livestock (Izaurralde et al., 2011). Increased temperature further caused direct heat stress to animals, which reduced pasture grazing time and feed intake where livestock prefer shaded areas instead of grazing or feeding, which greatly affected the body gain and milk production performance of animals. In agreement with this, heat stress resulting from climate change significantly reduced livestock feed intake (Chang-Fung-Martel et al., 2021). Kassahun (2016) further found that a unit increment in the thermal humidity index resulted in a reduction of milk yield by 0.2 kg for high-yielding animals. Households also observed the death of livestock due to drought and disease which are highly associated with climate change. This was in line with previous studies, which found drought resulting from climate change caused livestock mortality and yield loss (Yilma et al., 2009; Kasaye, 2010; Goughan and Cawsell-Smith, 2015). Households also mentioned that the frequency of livestock disease occurrence has been increasing over the past 10 to 15 years which is associated with frequent change in relative humidity.

Table 4: Climate change impacts on livestock production

Variables	Moist Weina Dega			Moist Kola		
	N	Index	Rank	N	Index	Rank
Caused feed shortage and quality reduction	73	0.45	1	87	0.46	1
Reduction of water resources (rivers/wells)	73	0.22	2	87	0.25	2
Increased heat stress due to increased temperature	73	0.12	4	87	0.17	3
Livestock mortality due increased diseases	73	0.21	3	87	0.12	4

N: number of households involved ranking

Climate Change Impacts on Herd Dynamics and Yield

Trends of livestock species dynamics over decades between moist Weina Dega and moist Kola were assessed through household interviews (Table 5). Nearly 30% of households in Moist Weina Dega and 45% in Moist Kola mentioned increasing trends for cattle, whereas nearly 59% in Moist Weina Dega mentioned that the number of cattle owned showed decreasing trends. Chi-square (X^2) showed that trends of cattle population over the years were significantly ($p<0.05$) different between agroecology where more decreasing trends were observed in moist Weina Dega agroecology. The decreasing trends in cattle numbers in moist Weina Dega could be associated with decreasing trends in grazing land, which is exacerbated by the need for farming land and decreasing trends for available feed resources. Nardone et al. (2010) reported that climate change reduced the carrying capacity of rangeland which ultimately affected livestock species dynamics. Stark et al. (2011) also found a reduction of 80% in livestock holdings in drought-prone areas. According to FDGs, households were forced to reduce the number of cattle owned due to decreased feed resource availability shifting to other livestock species that can withstand the effects of climate change. In this regard, households in the presented study mentioned that keeping more numbers of goats is more advantageous, mentioning that goats have a better capacity for adapting to climate change as they can browse feed resources that cannot be utilized by other livestock species. A previous study found that goats possess a better capacity to adapt to hot environments as compared with large ruminants (Joy et al., 2020). Many interviewed households; 90% in Moist Kola and 68% in most Weina Dega perceived increasing trends for goats which indicate an increment in goat population significantly ($p<0.0001$; $X^2 = 77.28$) observed by higher households in moist Kolla than moist Weina Dega. A study by Joy et al. (2020) mentioned that the selection of thermo-tolerant animals such as goats helps to combat climate change impacts.

The majority of households in both agro-ecologies reported no change in the number of donkeys owned, whereas more than half of the interviewed households reported an increase in the number of poultry owned; less than 10% in MWD and 5% in MK reported decreasing trends in the number of poultry owned, indicating that poultry is relatively unaffected by climate change and the means for adapting to it.

Table 5: Trends of livestock species dynamics over previous decades between agro-ecologies

Trends (N=160)	Cattle		Goat		Donkey		Poultry	
	MWD	MK	MWD	MK	MWD	MK	MWD	MK
Increasing (%)	31.5	44.8	68.49	89.7	15.6	29.9	58.4	56.3
No change (%)	9.59	26.4	27.4	10.3	71.4	64.4	29.9	40.2
Decreasing (%)	58.9	28.8	4.11	0	13	5.75	11.7	3.45
Chi-square	5.528275		77.28945		0.333721		16.07485	
Prob>ChiSq	0.0187		<0.0001		0.5635		0.0002	

MWD = Moist Weina Dega (n= 73), Moist Kolla (n=87). n is number of households interviewed

Perceived Climate Adaptation Strategies by Households

Through FGD and key informant interviews, different climate change adaptation strategies were explored and ranked during individual interviews (Table 6). Harvesting of rainwater during rainy seasons was reported as one of the major (ranking index = 0.2) options to overcome a shortage of water. Individual interviews and FGD discussions revealed that farmers have been harvesting and storing rainwater using traditional structures that will be used for drinking for cattle, humans (in severe cases), and occasionally growing fruits. Collection and harvesting of rainwater were also used as important climate change adaptation strategies in many drought-vulnerable parts of Africa (Ferrand et al., 2014; Swe et al., 2015; Opare, 2018). Livestock species diversification and proper feed management (feed storage and utilizing browsing species) were observed as other important adaptation strategies used by the community. Farmers stated that when there is a severe drought, they are forced to sell cattle and buy cereal crops to store; this strategy allows them to restock with money from stored crop sales. Keeping a greater number of goats was observed as the best strategy, as goats can withstand drought by utilizing browsing species that would not be consumed by cattle, which was in close agreement with previous studies conducted in Ethiopia (Wassie, 2015), which reported goats as climate-smart agricultural practices. Livestock diversification in line with the result of current was practiced by households in Ethiopia (Megersa et al., 2015; Menghistu et al., 2021). A study by Hoffmann, (2013) found that locally adopted and diversified livestock species can potentially increase yield, improve food security and adopt climate change. Participation in climate-smart technologies, such as increased beekeeping practices using different beehives (traditional and modern), has been reported to have significant benefits for farmers, as honey and its by-products are used as sources of food and income, both of which contribute significantly to reducing potential harm from climate change. Beekeeping was not only seen as a means to adopt climate change but also a means of climate change mitigation as it reduces the extent of cutting trees because traditional bee hives are usually placed on the trees. In line with this, a previous study found that beekeeping was seen as a good option to mitigate and adapt to climate change (Degu et al., 2021). Temporal migration of households toward the Lake Abaya area was also perceived as an important adaptation strategy by communities in the study area. The higher migration percentage (65%) was reported in a previous study of Borana pastoralists (Abate, 2016). Moving animals to other sites where mixed crop-livestock production prevails reported as a means of adapting to climate change in Kenya (Silvestri et al., 2012). Establishing drought-resistant livestock feed and using crop residues were also other climate change adaptation strategies that were used to overcome feed shortages for livestock. Maize straw and hair coat bean straw were crop residues used by all households, which was in agreement with previous studies (Karanja et al., 2016).

Table 6: Perceived climate change impacts adaptation strategies in the study area

Climate change adaptation strategy	Number of households ranking							Index	Rank
	1	2	3	4	5	6	7		
Collection and storage of rain water	51	61	26	12	3	1	1	0.20	1
Improved crop variety selection	28	23	34	14	4	3	2	0.13	5
Livestock species diversification	41	29	45	18	6	4	4	0.18	2
Income diversification	8	9	19	17	10	8	5	0.07	7
Establishing drought tolerant livestock feed	10	7	8	8	33	29	21	0.08	6
Feed storage and utilizing browsing species	12	18	11	48	57	65	63	0.18	2
Temporary migration (for feed and water)	10	13	17	43	47	50	64	0.16	4
Total	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**1**	

Factors Affecting Farmers' Adaptive Capacity

Factors affecting the adaptation capacity of farmers to climate change-related impacts were assessed through household interviews (Table 7). Then the households were asked to rank the perceived factors in order of their importance. Lack of appropriate and timely weather information was ranked as a major factor that greatly affected their preparedness to overcome the impacts of climate change. The results of individual interviews and FDGs indicated that a lack of weather information affected farmers' preparedness for forthcoming extreme events and land preparation for crop production and harvesting, which highly affected the agricultural production system and food security. Similarly, a previous study found households lacking access to weather information were reported as the main barriers in the process of climate change adaptation (Fosu-Mensah et al., 2012; Mubalama et al., 2020). Respondents also claimed that a lack of credit services was also seen as the main constraint affecting farmers' ability to adapt to climate change-related risks. According to respondents, much of the challenges occurred during drought periods, causing the loss of assets, whereas post-drought recovery was more challenging due to a lack of finance. Information gathered through the focused group discussion suggests that solving the problem of financial shortage and improving credit services during post-drought recovery greatly improves communities' capacity to adapt to the impacts of climate change. Silvestri et al. (2012) found that the capacity of households to adopt climate change is importantly constrained by a lack of credit services. Similarly, lack of improved technology and less development of infrastructure were among the important factors hindering the capacity of farmers to adapt to the impact of climate change. Improved technologies such as rainwater collection, long-term storage, and the utilization of feed-forage resources could improve the capacity for better adaptation and mitigation strategies. Field observation showed that most farmers collected and stored rainwater by digging a temporary hole. Under this condition, much of the stored water sinks to the ground, and other parts are lost through evaporation because of the lack of cover. Infrastructure, such as the lack of a suitable road to take farm products to market, was another problem preventing farmers from obtaining agricultural inputs on time and selling the products easily. The relative distance between a farmer's home and market, as well as the limited access farmers have to sell their products directly, increased the pressure on low-income people to respond to the effects of climate change. In agreement with this study, low market access for products was reported as an important factor reducing the capacity of producers to adapt the climate change (Silvestri et al., 2012). Farmers also indicated that the study area lacked strong institutional support and monitoring bodies and research that could carry out case studies, design policies, and implement them properly. Moreover, a previously degraded natural resource base and overexploitation of these resources currently worsen the issue of adaptation (Table 7)

Table 7: Factors affecting adaptation capacity of households to climate change impacts

Climate change adaptation strategy HH	Number of households ranking (n =160)							Index	Rank
	1	2	3	4	5	6	7		
Lack of weather information	66	58	41	9	5	0	0	0.24	1
Lack of credit services	40	32	50	14	7	1	0	0.18	2
Low-income source diversification	27	32	21	18	8	3	1	0.13	3
No modern technology to collect rainwater	10	15	19	28	10	12	5	0.10	6
Lack of strong institution/researches	8	12	11	29	28	24	23	0.10	6
Low infrastructural development	5	5	7	30	53	58	63	0.12	4
Degraded natural Resources	4	6	11	32	49	62	68	0.13	3

Institutional Support and Involvement

A previous study found that the presence of a complex mix of different institutional types can help address issues of climate change adaptation (Dietz et al., 2003). Amaru and Chhetri (2013) reported that sustainable adaptation to climate change requires widespread involvement and the integration of diverse institutions. A study by Mubaya et al. (2017) also reported that a mixture of public and private institutions plays a key role in facilitating local climate adaptation strategies in semi-arid areas of Zimbabwe. Despite a lack of coordination, some institutional support for households was observed during the survey and focused group discussions (Table 8). The main aims of these activities were to support and contribute to households' income generation, ultimately contributing to the adaptive capacity of households to disasters, including climate change. Capacity building on feed production and storage when feed is ample was one of the intervention areas mentioned for households (75%). Households interviewed mentioned that they have obtained capacity building and training on conserving feed when there is ample amount, planting drought-tolerant forage, and exploiting and using diversified locally available feed resources. During households' field observation, four main feed storage places were recognized, such as conserving feed on the ground, on the trees, in the home, and on the conserving bed. Conserving feed expected on the ground was mentioned as a good strategy as it reduced feed quality deterioration and unplanned forced consumption by livestock. It was observed that feed stored on the ground was subjected to unnecessary decomposition and forced consumption by livestock.

In addition to this, different livestock species, such as improved goat breed supply (31.9%), dissemination of improved poultry breed (25%), and supply of modern bee hives (35%), were supplied to households to contribute to their income and increase their adaptive capacity to climate change. A supply of improved crop seed varieties that can mature early and be able to grow in moisture stress (moist Kolla) was provided to 73% of the households interviewed.

Table 7: Institutional support and intervention area supporting households' capacity

Intervention area	MWD	MK	Overall
Capacity building on feed conservation (Yes %)	67.1	82.8	75.6
Supply of improved modern bee hives (Yes %)	34.2	35.6	35
Improved crop seed variety (Yes %)	89	59.8	73.1
Supply improved poultry breed (Yes %)	16.4	32.2	25
Plantation drought tolerant feed supply (Yes %)	46.6	54	50.6
Livestock breed improvement and supply (Yes %)	16.4	44.8	31.9

MWD = Moist Weina Dega (n=73), MK= Moist Kolla (n=87) agro ecology. n = number of households.

CONCLUSION

The findings of the present study showed that climate change was real and had far-reaching impacts on agricultural production in general and livestock production in particular. Interviewed households have seen rising environmental temperatures, unpredictable nature of rainfall, and increased frequency of extreme weather events as indicators of climate change. Climate change impacted livestock production by reducing the availability and quality of feed and water resources, impairing feed intake through heat stress, and causing livestock mortality. Households further believe the direct impacts of climate change on livestock production have significantly reduced livestock productivity and reproductive efficiency. Households used various livestock-related adaptation strategies, such as the collection and storage of rainwater, livestock species diversification, rearing animal species (goat) with more capacity for climate change impacts, better utilization and production of different feed resources, and temporary migration searching for feed and water. Lack of access to timely weather information and credit services, low levels of income diversity, a lack of modern technology assisting in the harvesting and storage of rainwater, low institutional support, and poor infrastructural development were major factors affecting the adaptive capacity of households. Provisions of timely weather information, research-based institutional support, and a more efficient rainwater collection strategy, along with the supply of input, would support farmers' adaptation to climate change impacts. Moreover, the support of households to adopt climate-smart agriculture would boost their capacity to adapt to climate change, food production, and environmental protection.

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Opportunities and Potentials of Potato (*Solanum tuberosum L.*,) Production and Future Prospects in Ethiopia

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Abstract:
In Ethiopia, potato production has increased during the "Meher" season as a result of improved varieties, being tolerant to major potato disease, late blight especially in the areas of major potato growing regions of the country. The objective of this review is to study the opportunities and potentials of potato production in Ethiopia. Ethiopia has the most potential of potato production because about 70% of the available agricultural land is suitable for potato production. However, the most challenges of potato production in Ethiopia are due to limited knowledge on seed and ware potato production techniques, lack of improved varieties and germplasm for diverse agro-ecologies, shortage of quality and healthy seed tuber/planting material, diseases and insect pests. So, the respective institutions and researchers should have to develop adapted varieties to different agro-ecological zone, high yielding, and resistance to late blight, early maturing with good quality for taste and market preference.

Keywords: Ethiopia, Potato, Potential, Opportunities

INTRODUCTION

Potato (Solanum tuberosum L.), a member of the family Solanaceae and the genus Solanum, is one of the most productive and widely grown food crops next to wheat, rice and maize (Golizadeh and Esmaeili, 2012). This crop is grown throughout the world and originated in the high Andes of South America and start to plant Lake Titicaca (Mulugeta and Dessalegn, 2013).

Potato (*Solanum tuberosum* L.) is one of the most productive food crops in terms of yields of edible energy and good quality protein per unit area per unit time (Jessie, 2017). Potato can be promoted as a healthy and versatile component of a nutritious and balanced diet including other vegetables and whole grain foods. From a human nutrition perspective, potatoes are an essential source of energy, protein, and micronutrients like iron and zinc. They also provide key nutrients to the diet including vitamin C, potassium, and dietary fibre. Likewise, in developing countries, it contributes to combat micronutrient deficiency, also referred to as hidden hunger, that is a major global public health problem affecting an estimated 2 billion people globally (Bailey *et al.*, 2015).

The annual world and African production of potato during 2018 was about 368.2 and 26 million tons, respectively (FAO, 2020). Potato is the fastest growing food crop in Sub-Saharan Africa and it is an important crop for food security in parts of Ethiopia by virtue of its ability to mature earlier than most other crops at time of critical food need (Haverkort *et al.*, 2012; Asresie *et al*., 2015). Ethiopia is one of the principal potatoes producing countries in Africa and probably displays a unique position for having the highest potential area for cultivating potatoes. In Ethiopia, potato is grown in a wide range of agro-ecological zones, throughout the year using different growing practices and is considered a "hunger breaking crop" because it can be grown and harvested when cereals don't mature for consumption other crops fail. Indeed, potato is the only food crop grown to any large extent in the dry season where rain-fall is erratic and unpredictable in the months of March through May (Kolech *et al.*, 2015). Egata (2019) described that among African countries, Ethiopia has the most potential of potato production because of the highlands comprises 70% of the country and home to higher percent of the population. Exploiting these production potentials will make the potato crop to play a key role in ensuring national food security (FAO, 2008). It is an important food crop after cereals, in human diet in developed as well as in developing countries (Kushwaha *et al*., 2014).

In Ethiopia, potato ranks first in the category of root and tuber crops (RTCs) in terms of area coverage and total production. Crop production survey results of private peasant holding of the year 2019/20 indicated that of the total land areas of about 248,357.51 hectares covered by RTCs, 70,362.22 hectare (~28.33%) and over 1 million tons of potato was produced (CSA, 2020) with an average national yield of 13.140 t ha-1 (CSA, 2019/20).

Currently, potato is produced mainly in the North western, Central and Eastern highlands of Ethiopia (Berhanu *et al*., 2011). Its production is constrained by a wide range of factors that resulting in low yields. These factors include lack of high yielding varieties tolerant to late blight, poor soil fertility, climatic limitation, inadequate seeds, lack of appropriate cultural practices, poor post-harvest management & storage problems, high cost of farm inputs, diseases and insect pests (Gebremedhin, 2013).

Opportunities and Potentials of Potato Production in Ethiopia

Introduction and evaluation of commercial varieties, introduction and evaluation of germplasm, generation of local population and recently introduction of advance materials are some of the strategies what we have followed to develop varieties widely adaptable, resistant/tolerant to different pests and stresses (Berga *et al.,* 1994). Accordingly, a number of variety trials were conducted in different corners of the country to catch different agro-ecologies of the potato growing areas. From these experiments widely adaptable, late blight resistant and high yielder (25-40 tons/ha) potato varieties were released and under production. So far, about 32 improved potato varieties were released and recommended by the National Potato Improvement Program (EAA, crop variety register, 2018).

Ethiopia has possibly the highest potential for potato production of any country in Africa. Among African countries, Ethiopia has the most potential of potato production because about 70% of the available agricultural land is suitable for potato production which is located at an altitude of 1,500 to 3,000 m.a.s.l with an annual rainfall between 600 and 1,200 mm (MOA, 2010). In recent years, potato production has dramatically increased in Ethiopia by about 96.54 %, from 349,000 tons in 1993 to 863,348 tons in 2010 (FAO, 2013).

Research has been conducted over years and a number of technologies have been selected, developed, released, adopted, and popularized since the establishment of research system in the country (Abebe, 2019). Among which variety development for different agro ecologies, crop pest management technologies, crop husbandry, post-harvest management and food quality appraisals are the major ones.

A number of potato varieties have been developed and released in the country. The first improved variety was released in 1987 (AL-624), since then more than 32 potato varieties were developed and released where as eight potato varieties developed in Europe were also evaluated for their adaptation and yield and registered for production in the country by agricultural research centers and Haramaya University (Gebremedhin, 2013).

Availability of improved technologies eg. Varieties, Management, IDM, etc., growing interests of public and non-governmental organizations in potato seed, increased farmer knowledge of potato seed production and management, high demand for quality seed, and high returns, good networking for intra-regional nuclear seed exchange , strong support of the International Potato center (CIP) and other stakeholders , conducive policy framework , high irrigation potential and conducive market proximity and niche and high yield per unit area as compared to other crops(Abebe,2019).

The emergence of specialized potato seed producers strongly linked with research institutions would enhance the performances and competitiveness of the potato sub-sector. Potato processing is another opportunity for operational upgrading. According to (Chernet Worku, 2019) Ethiopia is one of the largest markets for potatoes in Eastern Africa but relies on informal processing and import of processed products to satisfy its local demand.

Challenges of Potato Production in Ethiopia

The potential of producing sizable potato products appear to be influenced by several constraints. However, the main challenge is related with the seed system of the country. Potato is produced by small-scales individual farmers on fragmented lands following the informal seed system, where the producers used seed of inferior quality (Abebe, 2019). Seed tuber multiplication activities are mainly handled by individual farmers, cooperatives, which often lack even basic amenities for proper multiplication of seed tuber in sizable quantity, and high quality.

The most challenges of potato production in Ethiopia are due to limited knowledge on seed and ware potato production techniques, lack of improved varieties and germplasm for diverse agro-ecologies, shortage of quality and healthy seed tuber/planting material, diseases and insect pests (late blight, bacterial wilt, viruses and PTM), poor agronomic (spacing, fertility, ridging) and irrigation practices, limited capacity (human power, facility and infrastructure) and lack of formal seed system (dominated by informal seed system) (Abebe, 2019).

Weak extension linkage constrained by various financial and other resource limitations to promote and disseminate released potato varieties to the farmer's level. The relationship between farmers and extension services makes it easier for potato production technology to be adopted (Mamaru and Lemma, 2022). Access to Extension: Many research findings throughout time and location agree on the promising relationship between access to extension and technology adoption. Similarly, (Worku, 2014) stated that access to extension was positively influenced by adoption of improved potato technology package.

Towards Future Potato Research and Directions

- Supply of agricultural technologies such as new varieties, proper production practices
- Developing high yielding and diseases resistant varieties of potato for production.
- Development of varieties adaptable to different agro-ecological zone, resistance to late blight, early maturing with good quality for taste & market.

- Disease & insect pest management (IDM, IPM)
- In both rural- and industrial-based systems, innovations resulting from potato research should be incremental through a step-by-step improvement of an existing structure promoting technologies adapted to different agri-food systems.
- Support to the selection and promotion of locally adapted, demand-led potato varieties, combined with rapid seed multiplication techniques.
- Development of pest management options for a more rational use of pesticides and alternative practices such as biological control and decision support tools, combined with integrated cropping systems for sustainable production practices including water and soil fertility management

CONCLUSIONS AND RECOMMENDATIONS

Ethiopia has possibly the highest potential for potato production of any country in Africa. A number of potato varieties have been developed and released in the country. However, the weak extension linkage constrained by various financial and other resource limitations to promote and disseminate released potato varieties to the farmer's level. So, to improve potato production in Ethiopia supplying of agricultural technologies such as new varieties, proper production practices and strengthen extension linkage are paramount.

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Studies on the Effect of Rubber Effluent and NPK Applications Following Cropping with Rubber (*Hevea brasilliensis* Wild ex A. de Juss. Muell.Arg.) and Snake Tomato *Trichosanthes cucumerina* L. Haines) on Some Post Harvest Soil Chemical Properties in a Newly Established Rubber Plantations in Iyanomo

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Abstract:
The soil is the most important natural resource, because on it, the entire vegetation is dependent and by extension man, hence a field study was conducted in 2018 and 2019 cropping season to determine the effects of rubber effluent and NPK applications following cropping with rubber and snake on some post-harvest soil chemical properties in a newly established rubber plantation in Iyanomo. The treatments involved a combination of sole and intercropped combination with NPK and rubber effluent application rates laid out in a randomized complete block design in three replications. Pre- and Post-harvest soil analysis was carried out and data were collected on Particle size, Soil pH, Available Phosphorus, Exchangeable bases, total nitrogen and exchangeable acidity. Results of pre cropping soil analysis showed that soils of the experimental site were strongly acidic with values lower than critical level for some essential nutrients (table 1) while the post-harvest soil analysis showed that the soils benefited from the amendment with fertilizers (NPK and rubber effluent) (table 3a and b). The increase in soil pH, N, Ca, Mg, K, and Na and decrease in exchangeable acidity in plots fertilized with NPK and rubber effluent is attributed to the amending effects of the fertilizer. This finding implies that rubber effluent and NPK reduced soil acidity as the reaction changed from strongly acidic to moderately acidic.

Keywords: soils, fertilizer, rubber effluent, NPK, soil chemical properties and post-harvest

INTRODUCTION

Rubber (*Hevea brasiliensis* Wild ex A. de Juss. Muell.Arg.) is the world's number one source for natural rubber (Abolagba and Giroh, 2006). It belongs to the family Euphorbiaceae and is commercially grown in plantations for the white exudates (latex) which are commonly referred to as white gold (Asokan *et al.* 2000). There are about twenty species that are known to produce latex; of these about twelve belong to the Hevea genus and only *Hevea brasiliensis* is economically exploited (Asokan *et al.* 2000).

Trichosanthes cucmerina is among the traditional underutilized food crop of increasing importance in several parts of Africa including Ghana and Nigeria, mainly for the red fruit pulp used as a substitute for the regular tomato sauce (FAO, 1998). The scarcity and untold price hike that occur annually as a result of the off season of the tomato plant and recent invasion by *Tuta* *absoluta* that ravaged the entire tomato farm directed research efforts to looking for an alternative to the regular tomato. Intercropping snake tomato with natural rubber will help give the necessary awareness that the crop needs to bring it to lamp light.

The soil is the most important natural resource, because on it, the entire vegetation is dependent and by extension man. Man, directly depends on vegetation for food, hence it's necessary to preserve the top soil and help to improve its organic matter content in order to increase its nutrient providing ability (Defoer, 2002). The soils of the southern parts of Nigeria with few exceptions are characterized to have sub – optional nutrient status. Available phosphorus (P), Nitrogen (N) content, organic matter content and the available potassium (K) content are invariably low except for some soils of Northern Calabar (Onuwaje and Uzu, 1980).

Fertilizers, according to the IFA (2008), are materials that contain 5% or more of the three essential plant nutrients. They are soil amendments that guarantee the minimum percentages of Nitrogen, Phosphate and Potassium (Adrian *et. al*. 2014). Generally, Fertilizer among other advantages, improves soil nutrient, results in faster growth of crops, increases crop yield and improves the quality of fruits/crops, by making available the essential plant nutrients in readily available forms (EPA, 2013). Inorganic fertilizer application has been a major source of amendment and augmenting the soil, but the cost, availability and adulteration issues resulting from its use, growing concern on health hazards caused by the consumption of food crops produced by frequent application of chemical fertilizers as a result of the residual effect on the crop and the soil, among others are problems associated with chemical/inorganic fertilizer use (Carroll and Salt, 2004). Consequently, there is now a concerted effort to review the use of chemical fertilizers and to place more emphasis on the use of organic fertilizers such as green manure, compost manure, farm yard manure, effluents etc (Dhevagi, 2002; Hossain *et al.*, 2008).. Rubber factory effluent is considered a by-product (waste) from rubber processing factories and contains various plant growth substances including a number of elements such as N, K, P, Ca, Mg (Wilfred, 2002). Udoh *et al*., 2005; FAO, 2000 reported that rubber effluent contains substantial amount of plant nutrients particularly N and K. its use as soil nutrient amendment will help ameliorate the problem of disposal which has been a source of concern to rubber factory owners and environmentalist and also go a long way in the reduction of the cost of rubber production, improving soil fertility for the benefit of the crop and also take care of issues of water pollution and a substitute to inorganic fertilizer use. Hence this research work is directed towards evaluating the effect of rubber processing effluent and NPK15:15:15 as soil nutrient amendment in a rubber and Snake tomato intercrop and their effect on some postharvest soil chemical properties in a newly established rubber plantation.

MATERIALS AND METHODS

Experimental Site

The study was conducted in 2018 and 2019 cropping seasons at the Research farm of Rubber Research Institute of Nigeria (RRIN), Iyanomo near Benin City, Edo State, which lies within the Rain Forest zone of Nigeria. The study area falls between latitude 6°00 and 7°00'N and longitude 5°00' and 6°00'E. The rainfall pattern is bimodal with the peaks in the month of July and September but the highest in July and a short dry spell in August. The soils of this humid forest belt are mainly ultisols and the site is classified locally as kulfo series with pH range between 4.0 and 5.5 (RRIN, 1998)

Experimental Design and Field Layout

The treatments involved a combination of sole rubber and snake tomato and their intercropped combination with NPK (applied at 60kgNha^{-1}) and rubber effluent application rates (0, 50, 60 and 70kgNha^{-1}) laid out in a randomized complete block design in three replications. For rubber component in the intercrop, the treatments were:

- RE1RS-Rubber Effluent at application rate of 50 Kg N ha^{-1} cropped with rubber and snake tomato (Intercrop)
- RE1SR- Rubber Effluent at application rate of 50 Kg N ha^{-1} cropped with sole rubber
- RE2RS- Rubber Effluent at application rate of 60 Kg N ha^{-1} cropped with rubber and Snake tomato (Intercrop)
- RE2SR- Rubber Effluent at application rate of 60 Kg N ha^{-1} cropped with sole rubber
- RE3RS- Rubber Effluent at application rate of 70 Kg N ha^{-1} cropped with rubber and snake tomato (Intercrop)
- RE3SR- Rubber Effluent at application rate of 70 Kg N ha^{-1} cropped with sole rubber
- RSC- Rubber and snake tomato intercrop control
- RSNPK- 60 Kg NPK applied to rubber and snake tomato intercrop
- SRC- Sole Rubber Control
- SRNPK- 60 Kg NPK applied to sole rubber

Cultural Practices, Data Collection and Analysis

The snake tomato seeds were raised into seedlings in a polybag nursery filled with a mixture of top soil and poultry manure in ratio 3:1 for two weeks.

An experimental field measuring 26 by 60 m was cleared of the existing vegetation manually with the aid of cutlasses and hoes, the debris were packed out of the site, thereafter the field was marked out into plots measuring 3 by 7m with a metre pathway. The rubber effluent was applied immediately to the designated plots as per treatment two weeks prior to transplanting of rubber saplings, The pulled budded stump (young rubber) was placed in the hole in such a way that the budded patch is just above the ground level at a spacing of 3 by 7 m. The snake tomato seedlings were transplanted to designated plots at a spacing of 0.5 by 0.5 m, a week after the planting out of the rubber saplings. The NPK fertilizer was applied to the designated plots as per treatment two weeks after transplanting of snake tomato seedlings.

Standardization of Rubber Effluent

Rubber Effluent sourced from three Rubber Factories in Edo State (Odia, Okomu, and Osse Rubber Estate) and analyzed to check for possible variation in nutrient composition from the different sources, which can also give an idea of possible variation due to the type of clone. This was done using the standard laboratory standard (results of effluent analysis is shown in table 2). The Effluent was applied two weeks prior to transplanting of rubber sapling in order to decompose and equilibrate in the soil while NPK was applied two weeks after transplanting (WAT).

Soil Analysis

Prior to cropping with rubber and snake tomato, soil samples were randomly collected from the experimental site at a depth of 0 - 30 cm depth using auger and bulked together to form a composite sample. The composite soil sample was air-dried and sieved through a 2 mm mesh and analyzed for its physical and chemical properties using standard laboratory procedures. After harvest, soil samples were randomly collected from each plot separately and analyzed for its post-harvest chemical properties.

Particle size analysis was determined by hygrometer method (IITA, 1979), The soil pH was determined in 1:2 soils to water ratio using glass electrode digital pH meter, Available Phosphorus was extracted using Bray-1 solution and the phosphate in the extract was assayed calorimetrically by the molybdenum blue colour method and was determined by a spectrometer as described by IITA (1979). Exchangeable bases were extracted using 1N neutral ammonium acetate solution. Calcium and magnesium content of the solution were determined volumetrically by EDTA titration procedure by Houba *et al.* (1988). The level of calcium, potassium, and sodium was determined by flame photometer, the total nitrogen of the soil was determined by Micro kjeldahl procedure described by IITA (1979). The exchangeable acidity was determined by the KCL extraction and titration method of Houba *et al.* (1988).

Data Analysis

Data collected were analyzed with GENSTAT programme, using analysis of variance and significant differences among treatments means were separated using the LSD procedure at 0.05 level of probability.

RESULTS

The soils were strongly acidic and low in organic C, total N, available P and exchangeable Ca (Table 1). The Ca/Mg ratios were moderate. The soils were texturally sandy loam. The chemical analysis of the rubber effluent used for the study showed that it was moderately acidic with total dissolved solids, chemical oxygen demand and biochemical oxygen demand (Table 3). It contained total N, available P, organic C, K, Mg, Na and Ca in appreciable amount. However, the composition of the effluent varies with sources

Table 1: Pre-cropping characterization of some selected soils properties from the experimental site

Parameter	Site		Critical level	Fertility class
	New plantation	Existing plantation		
pH (H_2O) 1:1	5.4	5.4		SA
Organic carbon (g kg^{-1})	17.2	17.2	30.00 g kg^{-1} (Enwezor*et al*., 1989)	Low
Total nitrogen (g kg^{-1})	0.84	0.81	1.50 g kg^{-1} (Solulo and Osiname, 1981)	Low
C: N	20.48	21.23		
Available phosphorus (mg kg^{-1})	10.5	13	16.00 mg kg^{-1} (Adepetu*et al*., 1979)	Low
Exchangeable cation (cmol kg^{-1})				
Calcium	0.8	0.82	2.60 cmol kg^{-1} (Agboola and Corey, 1973)	Low
Magnesium	0.2	0.25		
Ca/Mg	4	3.4	3.00 (FDALAR, 1975)	Adequate
Potassium	0.16	0.17	0.16 - 0.20 (Hunter, 1975)	
Sodium	0.06	0.06		
Exchangeable acidity (cmol kg^{-1})				
Hydrogen	0.2	0.16		

Aluminium	0.1	0.11		
Particle size (gk g^{-1})				
Sand	886	886		NA
Silt	61	64		NA
Clay	39	36		NA
Textural class	Sandy loam	Sandy loam		NA
SA - Strongly acidic NA - Not applicable				

Table 2: Chemical composition of rubber effluent

Parameter	Odia	Okomu	Michellin
pH (H_2O)	6.2	6.2	6.4
Organic carbon (%)	29.6	25.8	15.96
Total nitrogen (%)	1.1	0.4	0.8
Phosphorus (%)	2.03	3.25	5
Potassium (%)	0.22	0.24	0.43
Magnesium (%)	0.38	0.38	0.4
Calcium (%)	0.49	0.5	0.57
Sodium (%)	0.04	0.05	0.06
zinc (%)	0.05	0.05	0.07
Copper (%)	0.02	0.02	0.03
Manganse (%)	0.08	0.08	0.09
Iron (%)	0.1	0.11	0.14
Chemical oxygen demand (mg l^{-1})	410	230	550
Biochemical oxygen demand (mg l^{-1})	250	270	870
Total dissolved solids (mg l^{-1})	760	160	330

Post-Harvest Soil Chemical Properties

The results of analysis of treated (NPK and rubber effluent) soil after cropping with snake tomato in sole and intercrop with rubber grown on newly established rubber plantation are presented in Tables 3 a and 3b. In both experiments and in the combined analysis, the highest pH was recorded in STNPK and RE3ST plots which were similar with all other treatments except RSC, RE2ST and RE2RS plots which had the lowest pH.

Plots cropped with RE1ST had the highest organic carbon in the first-year experiment which was identical with plots grown with RE1RS, RE1ST, RE3ST, RSC, RSNPK and STNPK but significantly different from plots cropped with RE2RS, RE2ST, RE3RS and STC. In the second-year experiment, organic carbon content varied between 8.84 and 19.24 g kg^{-1} for plots cropped with STC and RSNPK, respectively. However, organic carbon observed in the plot cropped with STC was identical with RSC, RE3RS, RE2ST and RE2RS plots. Plots grown with RSNPK had organic carbon comparable with the plots cropped with RE3ST and STNPK. In the combined analysis, RSNPK plots had the highest organic carbon content which was identical with RE3ST and RE1ST cropped plots while RE2ST cropped plot had the lowest organic carbon which was comparable with plots grown with RE2RS and STC. Total N in the first-year experiment ranged from 0.26 and 0.86 g kg^{-1} for plots grown with STNPK and RSC respectively. However, total N in RSC plot was similar with the plots grown with RSNPK, RE3ST, RE1ST and RE1RS. In the second-year experiment, the total N ranged from 0.65 and 1.17 g kg^{-1} for STC and RSNPK plots respectively. Total N recorded in RSNPK plot was not significantly higher than the total N content of RE3ST and RE3RS plots. When both experiments were combined, the plot cropped with RSNPK recorded the highest total N while plots grown with STC and STNPK had the lowest total N. Total N was higher in the second-year experiment than in the first-year experiment.

Available P was lowest in the plot grown with RSC in both experiments and in the combined analysis however, available P observed in RSC plot in combined analysis was comparable with the plot cropped with STC. The highest available P was recorded in STNPK plot and was identical with other treatments except plots with RSC and STC in both experiments and in the combined analysis. Available P was higher in the first-year experiment than in the second-year experiment.

The exchangeable Ca content in RE1RS plot was significantly different from other treatments except in the plot cropped with STNPK in the first experiment. The lowest exchangeable Ca was recorded in RE1ST plot. In the second experiment, the highest exchangeable Ca was recorded in RE3RS and STNPK plots while the lowest was recorded in RSC but identical with RE1ST and RE1RS plots. Plots cropped with STNPK and RE3RS had the highest exchangeable Ca while the lowest exchangeable Ca was observed in RE1ST plot but identical with the plot grown with RSC in the combined analysis. Exchangeable Ca was higher in the first-year experiment than in the second-year experiment.

Exchangeable Mg was not significantly different among treatments in the first-year experiment. The highest exchangeable Mg was observed in plots cropped with RE3RS and RE3ST in the second-year experiment. However, RE3RS and RE3ST plots were not significantly higher than RE2RS and RE2ST. RE3RS plot had the highest exchangeable Mg content which was only significantly different from RSC, RSNPK and STC plots in the combined analysis.

Exchangeable K was similar among treatments in the first-year experiment. In the second-year experiment, exchangeable K was highest in the plot grown with STNPK but comparable with RSNPK, RE3ST, RE2RS and RE3RS plots. The lowest exchangeable K content was recorded in STC and RSC plots but not significantly lower than RE2ST, RE1RS and RE1ST plots. Exchangeable K content was highest in plot cropped with STNPK which was significantly higher than STC, RSC and RE1ST plots when both experiments were pooled together.

All treatments in the first-year experiment had identical exchangeable Na content values. In the second-year experiment, exchangeable Na was highest in RE3RS plot but identical with RE3ST and RE2RS plots. Plot cropped with RSC had the lowest exchangeable Na which was comparable with RSNPK, STC, STNPK, RE1RS and RE1ST plots. In the combined analysis, RE3RS plot had the highest value which was identical with RE3ST plot. RE1RS, RSC and RSNPK cropped plots had the lowest values which were similar with RE1ST, RE2ST, STC and STNPK plots.

The exchangeable H^+ values were identical among treatments in the first-year experiment. In the second-year experiment, the exchangeable H^+ values were similar among the treatments except in STC and STNPK plots. The lowest exchangeable H^+ was observed in STC plot and identical with the values recorded in plots grown with RSC and STNPK. In the combined analysis, exchangeable H^+ ranged from 0.10 and 0.41 cmol kg^{-1} for plots cropped with RSNPK and RSC, respectively. However, RSC plot was comparable with STC, RE3ST, RE3RS, RE2RS, RE1ST and RE1RS plots.
The exchangeable Al^{3+} varied between 0.00 and 0.10cmol kg^{-1} for plots grown with STNPK and RE2ST, respectively. However, RE2ST plot had similar value with RE1ST and RSC plots. In the second-year experiment, STNPK and STC plots had the lowest exchangeable Al^{3+}values but identical with other treatments except RE2ST and RE2RS plot which had the highest exchangeable Al^{3+} values. In the combined analysis, exchangeable Al^{3+} ranged from 0.01 and 0.09cmol kg^{-1} for STNPPK and RE2ST plots, respectively.

Table 3a: post-harvest soil chemical properties following cropping of snake tomato treated with NPK and rubber effluent in newly established rubber plantation

Treatment	pH (H_2O)			Organic carbon ($g\ kg^{-1}$)			Total nitrogen ($g\ kg^{-1}$)			Available phosphorus ($mg\ kg^{-1}$)		
	1st	2nd year	Combined	1st	2nd year	Combined	1st	2nd year	Combined	1st	2nd year	Combined
RE1RS	6.20	6.20	6.20	9.78	9.40	9.59	0.80	0.76	0.78	10.20	9.43	9.82
RE1ST	6.00	6.00	6.00	10.87	9.46	10.17	0.79	0.73	0.76	10.50	9.41	9.96
RE2RS	5.80	5.80	5.80	8.59	8.87	8.73	0.70	0.82	0.76	9.25	9.36	9.30
RE2ST	5.60	5.60	5.60	8.39	8.89	8.64	0.68	0.81	0.75	9.36	9.39	9.38
RE3RS	6.20	6.20	6.20	8.38	9.84	9.11	0.67	1.03	0.85	9.10	9.49	9.30
RE3ST	6.30	6.30	6.30	10.14	19.17	10.15	0.81	1.11	0.96	9.36	9.62	9.49
RSC	5.70	5.70	5.70	10.20	9.21	9.71	0.86	0.75	0.80	8.75	8.40	8.57
RSNPK	6.00	6.00	6.00	10.14	19.24	10.19	0.81	1.17	0.99	9.36	10.04	9.70
STC	6.20	6.20	6.20	8.78	8.84	8.81	0.70	0.65	0.67	9.00	8.53	8.77
STNPK	6.30	6.30	6.30	9.58	10.15	9.87	0.26	0.96	0.61	10.60	10.84	10.62
Mean	6.03	6.03	6.03	9.49	9.51	9.50	0.71	0.88	0.79	0.79	9.43	9.49
$LSD_{(0.05)\ TRT}$	0.354	0.354	0.235	0.141	0.458	0.272	0.088	0.134	0.077	0.077	0.039	0.207
$LSD_{(0.05)}$ year	0.105			ns			0.034			0.092		

RE1RS - Rubber effluent at application rate of 50 kg N ha-1 cropped with rubber and snake tomato (Intercrop)
RE1ST - Rubber effluent at application rate of 50 kg N ha-1 snake tomato (Sole)
RE2RS - Rubber effluent at application rate of 60 kg N ha-1 cropped with rubber and snake tomato (Intercrop)
RE2ST - Rubber effluent at application rate of 60 kg N ha-1 snake tomato (Sole)
RE3RS - Rubber effluent at application rate of 70 kg N ha-1 cropped with rubber and snake tomato (Intercrop)
RE3ST - Rubber effluent at application rate of 70 kg N ha-1 snake tomato (Sole)
RSC - Rubber-snake tomato intercrop without NPK/rubber effluent treatment (control)
STC - Sole snake tomato (control)
STNPK - Sole snake tomato treated with 60 kg N ha-1 of NPK 15:15:15
RSNPK - Rubber-snake tomato treated with 60 kg N ha-1 of NPK 15:15:15

Table 3b: post-harvest soil chemical properties following cropping of snake tomato treated with NPK and rubber effluent in newly established rubber plantation.

Treatment	Exchangeable cation ($cmol\ kg^{-1}$)												Exchangeable acidity ($cmol\ kg^{-1}$)					
	Calcium				Magnesium		Potassium			Sodium			Hydrogen			Aluminum		
	1st	2nd year	Combined	1st	2nd year	Combined	1st	2nd year	Combined	1st	2nd year	Combined	1st	2nd year	Combined	1st	2nd year	Combined
RE1RS	1.3	0.78	1.04	0.23	0.18	0.21	0.25	0.19	0.22	0.13	0.11	0.12	0.2	0.11	0.16	0.03	0.04	0.03
RE1ST	0.85	0.77	0.81	0.2	0.15	0.18	0.22	0.17	0.2	0.14	0.12	0.13	0.15	0.12	0.13	0.08	0.05	0.07
RE2RS	0.84	0.85	0.85	0.18	0.2	0.19	0.2	0.27	0.24	0.13	0.15	0.14	0.12	0.12	0.12	0.06	0.07	0.07
RE2ST	0.73	0.8	0.76	0.18	0.2	0.18	0.2	0.22	0.21	0.12	0.14	0.13	0.35	0.12	0.24	0.1	0.08	0.09
RE3RS	1.23	1.24	1.24	0.2	0.23	0.22	0.23	0.28	0.25	0.15	0.17	0.16	0.1	0.11	0.11	0.03	0.04	0.04
RE3ST	0.9	1.12	1.01	0.19	0.23	0.21	0.2	0.29	0.25	0.13	0.16	0.15	0.1	0.12	0.11	0.05	0.05	0.05
RSC	0.84	0.73	0.79	0.12	0.1	0.11	0.24	0.16	0.2	0.13	0.1	0.12	0.75	0.07	0.41	0.07	0.04	0.05
RSNPK	0.9	1.12	1.01	0.19	0.15	0.17	0.2	0.29	0.24	0.13	0.11	0.12	0.1	0.1	0.1	0.05	0.04	0.04
STC	1.15	0.84	0.99	0.2	0.12	0.16	0.23	0.16	0.2	0.15	0.12	0.14	0.39	0.06	0.23	0.03	0.03	0.03
STNPK	1.25	1.24	1.25	0.23	0.18	0.2	0.24	0.3	0.27	0.14	0.12	0.13	0.05	0.08	0.07	0	0.03	0.01
Mean	1	0.95	0.97	0.19	0.17	0.18	0.22	0.23	0.23	0.14	0.13	0.13	0.23	0.1	0.17	0.05	0.05	0.05
$LSD_{(0.05)}$	0.078	0.058	0.047	ns	0.049	0.046	ns	0.077	0.064	ns	0.02	0.014	ns	0.039	0.14	0.02	0.021	0.014
$LSD_{(0.05)}$ year	0.021			ns			0.029						ns			ns		

Foot note
RE1RS - Rubber effluent at application rate of 50 kg N ha-1 cropped with rubber and snake tomato (Intercrop)
RE1ST - Rubber effluent at application rate of 50 kg N ha-1 snake tomato (Sole)
RE2RS - Rubber effluent at application rate of 60 kg N ha-1 cropped with rubber and snake tomato (Intercrop)

RE2ST - Rubber effluent at application rate of 60 kg N ha-1 snake tomato (Sole)
RE3RS - Rubber effluent at application rate of 70 kg N ha-1 cropped with rubber and snake tomato (Intercrop)
RE3ST - Rubber effluent at application rate of 70 kg N ha-1 snake tomato (Sole)
RSC - Rubber-snake tomato intercrop without NPK/rubber effluent treatment (control)
STC - Sole snake tomato (control)
STNPK - Sole snake tomato treated with 60 kg N ha-1 of NPK 15:15:15
RSNPK - Rubber-snake tomato treated with 60 kg N ha-1 of NPK 15:15:15

DISCUSSION

The soils of the experimental site were strongly acidic with values lower than critical level for some essential nutrients. This implied that the soil has low fertility status. Law-Ogbomo and Osaigbovo (2008) reported that most Nigerian soils are of low in native fertility owing to the highly weathered soils coupled with leaching and continuous cropping. Soil fertility is a very important factor in soil productivity in relation to nutrient and yield (Erhabor, 1995). Plants need supply of appropriate proportionate essential nutrients from the soil for optimum growth, development and yield. Low soil fertility status without adequate soil nutrient amendment will result in growth and yield depression due to nutrient deficiencies (Law-Ogbomo *et al*., 2020).

The analysis of the rubber effluent table2 showed variability depending on location. They were moderately acidic and contain N, P, K and Ca in appreciable quantity. The effluent has high concentration of organic carbon, COD and BOD at safe level. This finding is in agreement with Orhue *et al*. (2007) who reported highly significant amount of total suspended and dissolved solids, phosphate and total N in rubber effluent. Orhue and Osaigbovo, (2013) reported that rubber effluent had great potential as organic fertilizer and could be beneficial to arable crops without additional cost as effluent are waste product of rubber processing factories and its disposal has been a major concern to factory owners. This is an indication that rubber effluent which ought to be waste and pollutant to the environment can be made to be an avenue for wealth creation through its conversion to organic fertilizer.

The post-harvest fertility status of the soil was improved in line with reports by Law-Ogbomo *et al*. (2014) that reported increase in fertility status after fertilizer application which is a reflection of the availability of essential plant nutrients in NPK and rubber effluent. The increase in soil pH, N, Ca, Mg, K, and Na and decrease in exchangeable acidity in plots fertilized with NPK and rubber effluent is attributed to the amending effects of the fertilizer. This finding implies that rubber effluent and NPK reduced soil acidity as the reaction changed from strongly acidic to moderately acidic.

The decrease in exchangeable acidity might have led to higher soil pH. The increase in soil pH could have led to higher availability of exchangeable cations. The decrease in organic carbon in both the fertilized and unfertilized plots is not in conformity with the observation of Odedina *et al*. (2003), who reported that organic fertilizer increased soil organic matter.

The increase in N content in soil of rubber intercropped with snake tomato treated with NPK (RSNPK) compared to the sole snake tomato soils treated with NPK (STNPK) is a demonstration of N cycling as reported by Mbow *et al*. (2014). The decrease in available P compared to the initial concentrations could have resulted from decrease in soil organic carbon. The mineralization of available P due to microbial actions resulted in the production of organic acid, which make soil P available (Law-Ogbomo *et al*., 2016). The higher exchangeable Ca observed in RE3RS and RE2ST plots implies higher rate of mineralization of Mg as the fertilized plots contained more nutrient reserve than the unfertilized plots. The increase in exchangeable cation implies increase in the soil effective cation exchange capacity (ECEC) brought about through fertilizer application.

CONCLUSION AND RECOMMENDATION

The study shows that the soil analysis after the harvest of snake tomato showed that the soils benefited from the amendment with fertilizers (NPK and rubber effluent). Based on the findings from this study, snake tomato intercropping with rubber should be supplemented with fertilizer application to improve the fertility of the soil to sustain soil and higher growth of rubber and yield of snake tomato.

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On the Neutrosophic Algebraic Structures Involving Similarity and the Symmetry Properties on the Neutrosophic Interval Probability

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Abstract:
The neutrosophic interval statistical number (NISN) has been known to be very useful in expressing the interval values under indeterminate environments. One of the essential and so important useful as tools for measuring the degree of similarity between sets of given objects is the similarity measure. In this paper, neutrosophic numbers as well as the generalized Dice similarity measure for neutrosophic numbers for two sets are defined after which the axioms of fuzziness similarity and symmetry satisfying the NISN the properties were proved.

Keywords: Similarity, fuzziness, neutrosophic interval, symmetry Properties, generalized dice similarity measure (GDSM)

INTRODUCTION

The hesitant fuzzy linguistic information has been very useful as much as also being very applicable in finding lasting solutions and recommendations to multiple problems. Such like the attributes in decision making processes are often being finally resolved. As such, some algorithms can be developed in order for the utilization of the generalized Dice similarity measures giving required solutions. The renowned concept of neutrosophic statistics was founded and developed by the efforts of Prof. Dr. Florentin Smarandache, from the University of New Mexico, United States. This was originally started in1998, and then followed much later for further developments on it in 2014. Then, there was some introduction of the Neutrosophic

Descriptive Statistics (NDS). Sequel to this was the efforts put up by Prof. Dr. Muhammad Aslam, from the King Abdulaziz University, Saudi Arabia, who introduced the neutrosophic inferential statistics (NIS), Neutrosophic Applied Statistics (NAS), and Neutrosophic Statistical Quality Control (NSQC). in 2018. As it were, the Neutrosophic Statistics seems to be a generalization of Interval Statistics. This among others, is because of, while Interval Statistics is based on Interval Analysis, Neutrosophic Statistics is much based on Set Analysis (meaning every other kind of sets, and not only intervals as usual). The Neutrosophic Statistics is more elastic in style than the well-known and conversant Classical Statistics. Hence, if all the data and inference methods are determinate, then the Neutrosophic Statistics coincides with the Classical Statistics.

But, since in our world generally, we have more indeterminate data than those that are determinate. Therefore, there seems to be more neutrosophic statistical procedures which are needed than classical ones. The Dice similarity coefficient is a statistical tool. What it does is to measure the similarity between two given sets of data. It can also be referred to as the Sørensen–Dice index. (See [1]) We can also call it simply as the Dice coefficient. Some functions of which the similarity degree is expressed which involves certain items can be used in physical entities and phenomenon such as anthropology, automatic classification, psychology, ecology, information retrieval, citation analysis, numerical taxonomy and patterns recognition. The degree of dissimilarity or similarity between any given sets of objects plays a very important and vital role. space, most especially, in vector the cosine Jaccard, as well as the Dice similarity measures are often very useful in citation analysis, information retrieval, and also in automatic classification. In many cases, the Dice similarity measures as well as the asymmetric measures (also known as the projection measures) happen to be the special cases in some parameter values.

THE METHOD AS ADOPTED ON THE INTERVAL PROBABILITY AND THE NEUTROSOPHIC STATISTICAL NUMBER

The concepts of neutrosophic statistics seems to extend the classical statistics. It deals with set values instead of crisp values. In most of the classical statistics equations and formulas, one simply replaces several numbers by sets. Consequently, instead of operations with numbers, one uses operations with sets. One normally replaces the parameters that are indeterminate (imprecise, unsure, and even completely unknown).

Looking at the Neutrosophic interval statistical number, it is supposed to be a form of interval sets or range of certain values or other common entities. In most cases, it can be in the form of intervals (such kinds of intervals can be of the form known as closed, half closed, half open or open) and mostly represented as: [x, y], [x, y), (x, y], and (x, y), where x and y are the usual real numbers.

The neutrosophic interval probability (NIP has been defined in a range given by: $[V^L, V^U]$ of individuals in the given sample. (See [4, and 5]) The form of a NIP form can be clearly expressed as follows: D = < $[V^L, V^U]$, (D_T, D_I, D_F)>, where, are the true probability is given by D_T, while that of indeterminate, and false probabilities are given as D_I and D_F. Each of these could be found respectively in the range of the determinate, indeterminate, and failure. Now for each trial data, we have that the neutrosophic interval probability defined in an equational form as follows:

$$D_T = \frac{n_T}{n}, D_T = \frac{n_T}{n} \text{ and } D_T = \frac{n_T}{n}$$

Here, n is the total number of the individuals totals n. are the Some number of samples falls in the interval $[v_m - \sigma, v_m + \sigma]$. This is denoted by n_T.For n_I, the interval is given by: $[v_m - 3\sigma, v_m - \sigma]$ and for n_F, it is given by : $(v_m + \sigma, v_m + 3\sigma)$, which is the number of the rest samples. Also, v_m is the statistical mean value while the standard deviation is represented by σ. The addition of all the probabilities equals 1. Efforts were intensified to clarify the proof the axioms of fuzziness similarity and symmetry satisfying the NISN the properties were proved (see also, [6, 7, and 8]).

On the Numerical Neutrosophic Numbers

Here, (in this case, in a way to approximate the imprecise data the indeterminacy "I" is always given as real subsets. Hence, making it more general than the interval. This is because "I" may be given as any subset. Take instance, N = 8 + 6I, where "I" is in the discrete hesitant subset {0.4, 0.9, 6.4, 55.6} in this case having only four elements, which is not part of interval analysis (such as in statistics). But for the interval statistics, the interval [0.4, 55.6] is taken so as to include those given numbers which fall within the given range of the intervals. But then, with this, the level of the uncertainty seems to increase so much considerably. Now, in cases where the "I" is an interval given as I = [I_1, I_2], with $I_1 \leq I_2$, we are going to have that N = x + yI. This actually coincides with the interval which is given by: N = [x + yI_1, x + yI_2]. (Please, see [10] for more details)

THE FUZZINESS, SIMILARITY AND THE SYMMETRY PROPERTIES

The Fuzziness Condition

$$A1.\ 0 \leq E(R_A, R_B) \leq 1$$

Definition 1: (see [3]):

For a classical Neutrosophic Number, the standard form can be expressed as $a+bI$. Also, a as well as b are real number coefficients. I is the indeterminacy, whence $0 \cdot I = 0$ and $I^2 = I$ are both true. Hence, we have that $I^n = I$, and this is true for each of the positive integer given by *n*. Now, we call $a+bI$ the Neutrosophic Real Number whenever the two arbitrary coefficients *a* as well as *b* are real numbers.

Furthermore, it should be well noted here, that we have literal neutrosophic numbers, a+bI, where I = letter, and I^2 = I, and numerical neutrosophic numbers, a+bI, where I = a real subset (normally interval). But herein $I^2 \neq I$.

Take for example, the following, as quoted from [3]:

a. $[10.2, -8]^2 = [-10.2, -8] \cdot [-10.2, -8] = [64, 104.04]$.
b. $[-14.25, -9]^2 = [(-9)^2, (-14.25)^2] = [81, 203.0625]$
c. $[13.8, 16]^2 = [13.8^2, 16^2] = [190.44, 256]$
d. $[1.8, 10]^2 = [1.8^2, 10^2] = [3.24, 100]$

Clearly, from this analysis, $I^2 \neq I$.

Definition 2: (see [9]):

An important measure about the similarity in between two objects can sometimes be referred to as the Similarity measures (SMs). In this case, a special kind of such measures is often applied to be used mostly in comparing objects is the generalized dice similarity measure (GDSM).

Definition 3: (see [3]):

Suppose that $R_A = a_A + b_A I$……… (i) and $R_B = a_B + b_B I$………(ii) are neutrosophic numbers, such that each of a_A, b_A, a_B, and $b_B \geq 0$. We define a generalized dice similarity measure in this manner in between R_A and R_B:

$$E(R_A, R_B) = \frac{2R_A.R_B}{|R_A|^2 + |R_B|^2} = L \text{ (say)}$$

Then,

$$L = 2\text{x}\frac{(a_A + \inf(b_A I))(a_B + \inf(b_B I) + (a_A + sup(b_A I))(a_B + \sup(b_B I)}{(a_A + \inf(b_A I)^2 + (a_A + \sup(b_A I)^2 + (a_B + \inf(b_B I)^2 + (a_B + \sup(b_B I)^2}$$

(Note that each of$(a_A + \inf(b_A I))$, $(a_B + \inf(b_B I)$, $(a_A + sup(b_A I))$, and $(a_B + \sup(b_B I)$ is a real number since each of the components such as a_A, $\inf(b_A I)$, a_B, $\inf(b_B I)$,etc. is rea number).

We have,

$$L = \frac{2(a_A + \inf(b_A I))(a_B + \inf(b_B I) + 2(a_A + sup(b_A I))(a_B + \sup(b_B I)}{[(a_A + \inf(b_A I)^2 + (a_B + \inf(b_B I)^2] + [(a_A + \sup(b_A I)^2 + (a_B + \sup(b_B I)^2]}$$

$$= \frac{2(a_A + \inf(b_A I))(a_B + \inf(b_B I) + 2(a_A + sup(b_A I))(a_B + \sup(b_B I)}{2(a_A + \inf(b_A I))(a_B + \inf(b_B I) + 2(a_A + sup(b_A I))(a_B + \sup(b_B I) + [(a_A + \inf(b_A I)) + (a_B + \inf(b_B I)]^2 + [(a_A + sup(b_A I)) + (a_B + \sup(b_B I)]^2}$$

Dividing through by $2(a_A + \inf(b_A I))(a_B + \inf(b_B I) + 2(a_A + sup(b_A I))(a_B + \sup(b_B I)$

We have: $\frac{1}{1+[(a_A + \inf(b_A I)) + (a_B + \inf(b_B I)]^2 + [(a_A + sup(b_A I)) + (a_B + \sup(b_B I)]^2}$(k)

(Here, it should be observed that since $(X + Y)^2 = X^2 + Y^2 + 2XY$, it implies that $X^2 + Y^2 = (X + Y)^2 - 2XY$)

Obviously, this is a positive number which is greater than 0. Hence, this satisfies the left-hand side of the inequality. i.e., $0 \leq L = E(R_A, R_B)$

Now, to show that L is less or equal to 1, observe that the denominator is positive since the addition of positive numbers is positive, whence the square of any real number is positive. We thus prove this by contradiction. Assume that $L \nleq 1$.

Let $X^2 = [(a_A + \inf(b_A I)) + (a_B + \inf(b_B I)]^2 + [(a_A + sup(b_A I)) + (a_B + \sup(b_B I)]^2$We have that $L = \frac{1}{1+X^2} > 1$, we have that $1 > 1 + X^2 \Longrightarrow X^2 < 0$. A contradiction ($\Longrightarrow\Longleftarrow$). Hence, $0 \leq E(R_A, R_B) \leq 1$. This satisfies A1■

The Similarity Condition
A2. $E(R_A, R_B) = 1$ if $R_A = R_B$

Proof:
($\Leftarrow$) Assume that $R_A = R_B = R = a + bI$

Then, by definition,

$$E(R_A, R_B) = E(R, R) = \frac{2R_A.R_B}{|R_A|^2 + |R_B|^2} = \frac{2R.R}{|R|^2 + |R|^2}$$

$$2\text{x}\frac{(a + \inf(bI))(a + \inf(bI) + (a + sup(bI))(a + \sup(bI)}{(a + \inf(bI)^2 + (a + \sup(bI)^2 + (a + \inf(bI)^2 + (a + \sup(bI)^2}$$

$$= \frac{2(a + \inf(bI))(a + \inf(bI) + 2(a + sup(bI))(a + \sup(bI)}{(a + \inf(bI)^2 + (a + \sup(bI)^2 + (a + \inf(bI)^2 + (a + \sup(bI)^2}$$

$$= \frac{2(a + \inf(bI))(a + \inf(bI) + 2(a + sup(bI))(a + \sup(bI)}{2(a + \inf(bI)^2 + 2(a + \sup(bI)^2}$$

$$= \frac{2(a + \inf(bI)^2 + 2(a + \sup(bI)^2}{2(a + \inf(bI)^2 + 2(a + \sup(bI)^2} = 1.$$

($\Rightarrow$) Assume that $E(R_A, R_B) = \frac{2R_A.R_B}{|R_A|^2 + |R_B|^2} = 1$. Then, $2R_A.R_B = |R_A|^2 + |R_B|^2$

$$\Rightarrow 2(a_A + \inf(b_A I))(a_B + \inf(b_B I) + (a_A + sup(b_A I))(a_B + \sup(b_B I)$$

$$=(a_A + \inf(b_A I)^2 + (a_A + \sup(b_A I)^2 + (a_B + \inf(b_B I)^2 + (a_B + \sup(b_B I)^2$$

$$\Rightarrow 2(a_A + \inf(b_A I))(a_B + \inf(b_B I) + 2(a_A + sup(b_A I))(a_B + \sup(b_B I)$$

$$=(a_A + \inf(b_A I)^2 + (a_B + \inf(b_B I)^2 + (a_A + \sup(b_A I)^2 + (a_B + \sup(b_B I)^2$$

Equating components, we have,

$$2(a_A + \inf(b_A I))(a_B + \inf(b_B I) = (a_A + \inf(b_A I)^2 + (a_B + \inf(b_B I)^2 \text{ And} 2(a_A + sup(b_A I))(a_B + \sup(b_B I) = (a_A + \sup(b_A I)^2 + (a_B + \sup(b_B I)^2$$

$$\Rightarrow (a_A + \inf(b_A I)) = (a_B + \inf(b_B I) = (a + \inf(bI) \text{ and } (a_A + sup(b_A I)) = (a_B + \sup(b_B I) = (a + \sup(bI) \text{ (say)}$$

$\Rightarrow R_A = R_B$ with the condition that:

$$\begin{cases} 2(a_A + \inf(b_A I))(a_B + \inf(b_B I) = (a_A + \inf(b_A I)^2 + (a_B + \inf(b_B I)^2 \\ \text{And} 2(a_A + sup(b_A I))(a_B + \sup(b_B I) = (a_A + \sup(b_A I)^2 + (a_B + \sup(b_B I)^2 \end{cases}$$

This satisfies A2 ■

The Symmetry Condition
P3. E (R_A, R_B) = E (R_B, R_A)

Proof:
We have that,

$$E(R_A, R_B) = \frac{2R_A.R_B}{|R_A|^2 + |R_B|^2}$$

$$= 2\text{x}\frac{(a_A + \inf(b_A I))(a_B + \inf(b_B I) + (a_A + sup(b_A I))(a_B + \sup(b_B I)}{(a_A + \inf(b_A I)^2 + (a_A + \sup(b_A I)^2 + (a_B + \inf(b_B I)^2 + (a_B + \sup(b_B I)^2}$$

$$= 2\text{x}\frac{(a_B + \inf(b_B I)(a_A + \inf(b_A I)) + (a_B + \sup(b_B I)(a_A + sup(b_A I))}{(a_B + \inf(b_B I)^2 + (a_B + \sup(b_B I)^2 + (a_A + \inf(b_A I)^2 + (a_A + \sup(b_A I)^2}$$

$$= \frac{2R_B.R_A}{|R_B|^2 + |R_A|^2} = E(R_B, R_A).$$ This satisfies A3 ■

The Fuzzy Condition
A4. $0 \leq E(A, B) \leq 1$

Definition 3: (see [2]):
Let A = {R_{A1}, R_{A2}, ..., R_{An}} and B = {R_{B1}, R_{B2}, ..., R_{Bn}}be two sets which are neutrosophic numbers, and that $R_{Ak} = a_{Ak} + b_{Ak}I$, $R_{Bk} = a_{Bk} + b_{Bk}I$ such that (k = 1, 2, ..., n). In addition, each of a_{Aj}, b_{Aj}, a_{Bj} and $b_{Bj}$is positive. i.e., ≥ 0. Then, the number which is called the generalized Dice similarity measure in between the sets A and B can are usually being found by using the expansion given as:

$$E(A, B) = \sum_{j=1}^{n} w_j \frac{2R_{Aj}.R_{Bj}}{|R_{Aj}|^2 + |R_{Bj}|^2}$$

$$= 2\sum_{j=1}^{n} w_j \frac{(a_{Aj}+\inf(b_{Aj}I))(a_{Bj}+\inf(b_{Bj}I)+(a_{Aj}+sup(b_{Aj}I))(a_{Bj}+\sup(b_{Bj}I)}{(a_{Aj}+\inf(b_{Aj}I)^2+(a_{Aj}+\sup(b_{Aj}I)^2+(a_{Bj}+\inf(b_{Bj}I)^2+(a_{Bj}+\sup(b_{Bj}I)^2}$$

$$= 2\left(w_1 \frac{(a_{A1}+\inf(b_{A1}I))(a_{B1}+\inf(b_{B1}I)+(a_{A1}+sup(b_{A1}I))(a_{B1}+\sup(b_{B1}I)}{(a_{A1}+\inf(b_{A1}I)^2+(a_{A1}+\sup(b_{A1}I)^2+(a_{B1}+\inf(b_{B1}I)^2+(a_{B1}+\sup(b_{B1}I)^2}\right)$$

$$+ 2\left(w_2 \frac{(a_{A2}+\inf(b_{A2}I))(a_{B2}+\inf(b_{B2}I)+(a_{A2}+sup(b_{A2}I))(a_{B2}+\sup(b_{B2}I)}{(a_{A2}+\inf(b_{A2}I)^2+(a_{A2}+\sup(b_{A2}I)^2+(a_{B2}+\inf(b_{B2}I)^2+(a_{B2}+\sup(b_{B2}I)^2}\right)$$

$$+\cdots + 2\left(w_k \frac{(a_{Ak}+\inf(b_{Ak}I))(a_{Bk}+\inf(b_{Bk}I)+(a_{Ak}+sup(b_{Ak}I))(a_{Bk}+\sup(b_{Bk}I)}{(a_{Ak}+\inf(b_{Ak}I)^2+(a_{Ak}+\sup(b_{Ak}I)^2+(a_{Bk}+\inf(b_{Bk}I)^2+(a_{Bk}+\sup(b_{Bk}I)^2}\right)$$

$$+\cdots 2\left(w_n \frac{(a_{An}+\inf(b_{An}I))(a_{Bn}+\inf(b_{Bn}I)+(a_{An}+sup(b_{An}I))(a_{Bn}+\sup(b_{Bn}I)}{(a_{An}+\inf(b_{An}I)^2+(a_{An}+\sup(b_{An}I)^2+(a_{Bn}+\inf(b_{Bn}I)^2+(a_{Bn}+\sup(b_{Bn}I)^2}\right)$$

Now, let

$$Q = 2\sum_{j=1}^{n} w_j \frac{(a_{Aj}+\inf(b_{Aj}I))(a_{Bj}+\inf(b_{Bj}I)+(a_{Aj}+sup(b_{Aj}I))(a_{Bj}+\sup(b_{Bj}I)}{(a_{Aj}+\inf(b_{Aj}I)^2+(a_{Aj}+\sup(b_{Aj}I)^2+(a_{Bj}+\inf(b_{Bj}I)^2+(a_{Bj}+\sup(b_{Bj}I)^2}$$

$$= \sum_{j=1}^{n} w_j \frac{2(a_{Aj}+\inf(b_{Aj}I))(a_{Bj}+\inf(b_{Bj}I)+2(a_{Aj}+sup(b_{Aj}I))(a_{Bj}+\sup(b_{Bj}I)}{2(a_{Aj}+\inf(b_{Aj}I))(a_{Bj}+\inf(b_{Bj}I)+2(a_{Aj}+sup(b_{Aj}I))(a_{Bj}+\sup(b_{Bj}I)+[(a_{Aj}+\inf(b_{Aj}I))+(a_{Bj}+\inf(b_{Bj}I)]^2+[(a_{Aj}+sup(b_{Aj}I))+(a_{Bj}+\sup(b_{Bj}I)]^2}$$

Dividing through by

$$2(a_{Aj}+\inf(b_{Aj}I))(a_{Bj}+\inf(b_{Bj}I)+2(a_{Aj}+sup(b_{Aj}I))(a_{Bj}+\sup(b_{Bj}I)$$

We have that:

$$Q = \sum_{j=1}^{n} w_j \frac{1}{1+[(a_{Aj}+\inf(b_{Aj}I))+(a_{Bj}+\inf(b_{Bj}I)]^2+[(a_{Aj}+sup(b_{Aj}I))+(a_{Bj}+\sup(b_{Bj}I)]^2}$$

(Here, $\sum_{j=1}^{n} w_j = w_1 + w_2 + w_3 + w_n = 1$) (*)

And clearly, the fraction is a positive number which is greater than 0. Hence, this satisfies the left-hand side of the inequality. i.e., $0 \leq Q = E(A, B)$

Now, to show: $Q \leq 1$, We thus prove this by contradiction. Assume that $Q \nleq 1$.

Let

$$Yj^2 = [(a_{Aj}+\inf(b_{Aj}I))+(a_{Bj}+\inf(b_{Bj}I)]^2+[(a_{Aj}+sup(b_{Aj}I))+(a_{Bj}+\sup(b_{Bj}I)]^2$$

We have that

$$Q = \frac{1}{1+Y_j^2} > 1,$$

we have that

$$1 > 1 + X^2 \Longrightarrow X^2 < 0. \text{ A}$$

We have that

$$Q = \sum_{j=1}^{n} w_j \frac{1}{1+Y_j^2} > 1,$$

we have that

$$1 > 1 + X^2 \Rightarrow X^2 < 0. \text{ A}$$

$$w_1 \frac{1}{1+Y_1^2} + w_2 \frac{1}{1+Y_2^2} + w_3 \frac{1}{1+Y_3^2} + \cdots + w_n \frac{1}{1+Y_n^2} > 1$$

(And since $w_1 + w_2 + w_3 + w_n = 1$, let $w_j = \frac{1}{x_j^2}$)

We have that

$$Q = \frac{1}{x_1^2} \frac{1}{(1+Y_1^2)} + \frac{1}{x_2^2} \frac{1}{(1+Y_2^2)} + \frac{1}{x_3^2} \frac{1}{(1+Y_3^2)} + \cdots + \frac{1}{x_n^{2(}} \frac{1}{1+Y_n^2)} > 1$$

$$\frac{1}{x_1^2(1+Y_1^2)} + \frac{1}{x_2^2(1+Y_2^2)} + \frac{1}{x_3^2(1+Y_3^2)} + \cdots + \frac{1}{x_n^2(1+Y_n^2)} > 1$$

Definitely, the LHS is not greater than 0. Hence, the initial assumption is false, and thus

$$0 \leq Q = \sum_{j=1}^{n} w_j \frac{1}{1+[(a_{Aj}+\inf(b_{Aj}I)) + (a_{Bj}+\inf(b_{Bj}I)]^2 + [(a_{Aj}+sup(b_{Aj}I)) + (a_{Bj}+\sup(b_{Bj}I)]^2} = E(A, B) \leq 1$$

This satisfies A4 ■

The Similarity Condition
A5. E (A, B) = 1 provided that A and B are equal

Proof:
(⇐) If we assume that A and B are equal and are equal to R

Then,

$$E(A, B) = E(R, R) = \frac{2R.R}{|R|^2 + |R|^2}$$

$$= 2\sum_{j=1}^{n} w_j \frac{(a_{Rj}+\inf(b_{Rj}I))(a_{Rj}+\inf(b_{Rj}I) + (a_{Rj}+sup(b_{Rj}I))(a_{Rj}+\sup(b_{Rj}I)}{(a_{Rj}+\inf(b_{Rj}I)^2 + (a_{Rj}+\sup(b_{Rj}I)^2 + (a_{Rj}+\inf(b_{Rj}I)^2 + (a_{Rj}+\sup(b_{Rj}I)^2}$$

$$= \sum_{j=1}^{n} w_j \frac{2(a_{Rj}+\inf(b_{Rj}I))^2 + 2(a_{Rj}+\sup(b_{Rj}I)^2}{2(a_{Rj}+\inf(b_{Rj}I)^2 + 2(a_{Rj}+\sup(b_{Rj}I)^2}$$

$$= \sum_{j=1}^{n} w_j = w_1 + w_2 + w_3 + w_n = 1 \text{ by } (*) \blacksquare$$

The Symmetry Condition
A6.E[A, B] = E [B, A]

$$D(A, B) = \sum_{j=1}^{n} w_j \frac{2R_{Aj}.R_{Bj}}{|R_{Aj}|^2 + |R_{Bj}|^2}$$

$$= 2\sum_{j=1}^{n} w_j \frac{(a_{Aj}+\inf(b_{Aj}I))(a_{Bj}+\inf(b_{Bj}I)+(a_{Aj}+sup(b_{Aj}I))(a_{Bj}+\sup(b_{Bj}I)}{(a_{Aj}+\inf(b_{Aj}I)^2+(a_{Aj}+\sup(b_{Aj}I)^2+(a_{Bj}+\inf(b_{Bj}I)^2+(a_{Bj}+\sup(b_{Bj}I)^2}$$

$$= 2\sum_{j=1}^{n} w_j \frac{(a_{Bj}+\inf(b_{Bj}I)(a_{Aj}+\inf(b_{Aj}I))+(a_{Bj}+\sup(b_{Bj}I)(a_{Aj}+sup(b_{Aj}I))}{(a_{Bj}+\inf(b_{Bj}I)^2+(a_{Bj}+\sup(b_{Bj}I)^2+(a_{Aj}+\inf(b_{Aj}I)^2+(a_{Aj}+\sup(b_{Aj}I)^2}$$

$$= \sum_{j=1}^{n} w_j \frac{2R_{Bj}.R_{Aj}}{|R_{Bj}|^2+|R_{Aj}|^2} = D(B, A) \text{ This satisfies P6 } \blacksquare$$

APPLICATIONS

So far, it can be deduced and inferred that the fuzziness, similarity and the symmetry properties on the neutrosophic interval probability is of utmost importance and thus could be made applicable in such kind of similar cases.

CONCLUSION

Finally, the proofs of the Fuzziness, Similarity and The Symmetry Properties on The Neutrosophic Interval Probability have been fully given

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CONFLICTS OF INTEREST

The author hereby declares that there is no competing of interests whatsoever before, during and after the course of the production and publication of this work

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Early Warning and Information Communication System: A Review Paper

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Abstract:
Climate change and increased risk of disasters have amplified the vulnerability of human and ecological systems, and the Sendai Framework for Disaster Risk Reduction recommends developing and strengthening a people-centered early warning system. This paper reviewed the practices of early warning systems to compile the finding of different studies. The review was based on the review of journals and eight studies conducted in different parts of the world on early warning systems and information communication was included for review. According to the review, the formal early warning system is little known among the communities and is unreliable and inaccessible. Monitoring and warning services of early warning systems have limitations and communication follows a top-to-bottom direction that hinders reaching their intended community members and many households lack access to early warning information. Besides, the early warning system faces challenges in providing sufficient and appropriate responses. As a result, this review will provide information to policymakers, planners, and other interested parties in order for them to act and strengthen early warning systems. Consequently, countries should develop, evaluate, and enhance a community-based early warning system that fulfills the expectations of the community.

Keywords: Disaster, Early Warning System, Risk Knowledge, Monitoring and Warning service, Dissemination and Communication, Response Capacity, CBEWS: Community-Based Early Warning System, CPCs: Civil Protection Committees, DCCMS: Department of Climate Change and Metrological Services, DRR: Disaster Risk Reduction, DWR: Department of Water Resources, EOC: Emergency Operations Centers, EWS: Early Warning System, GDPC: Global Disaster Preparedness Center, MO: Metrological Organization, NGOs: Non-Governmental Organizations, ODM: Office of Disaster Management, SMO: State Metrological Organization, WMO: World Metrological Organization

INTRODUCTION

Climate change and increased risk of disasters have amplified the vulnerability of human and ecological systems. The vulnerability and risk associated with hazards are unevenly distributed, with countries in the Global South being more vulnerable due to limited capacities to cope and adapt (Rana et al., 2021), and the Sendai Framework for Disaster Risk Reduction suggests developing and enhancing a people-centered early warning system that focuses on at-risk individuals, communities, and organizations and aims to allow quick action and readiness in the face of potential disasters (Chinguwo & Deus, 2022). An Early Warning System is a nonstructural measure designed to reduce the impact of hazard such as flooding, by providing timely and effective information to those exposed to the hazard (Ali et al., 2009), and the United Nations

International Strategy for Disaster Reduction (UNISDR) defines the EWS as a system that enables people to take action to avoid or reduce their risk and prepare for an effective response (UNISDR, 2009). Warning services, risk knowledge, monitoring, dissemination, communication capabilities and evaluation are part of the EWSs which does not confine itself to predicting a disaster (Ali et al., 2009; Basher, 2006).

EWSs are considered to be an essential element in reducing the risk of disaster for saving lives since they trigger actions that lead to prevention, mitigation and reduction of risks such as death, injury, damage or loss (Damtie & Asmare, 2020; Oktari et al., 2014; Rana et al., 2021). It involves hazard monitoring, forecasting, prediction, risk assessment, communication, and preparedness activities (UNISDR, 2009). Early warning is a question of saving life and property. In a country such as Ethiopia, which is vulnerable to multi-hazards, its importance is undeniable (Damtie & Asmare, 2020).

Early warning systems are monitoring devices designed to avoid or mitigate the impact posed by a threat (Medina-Cetina & Nadim, 2008) and helps communities prepare for and respond to disasters (Rana et al., 2021). An efficient EWS should consider the risks faced by the exposed communities and incorporate short-term or long-term mitigation measures (Basher, 2006).

In fact, the EWSs are still limited in their ability to forecast all types of hazard, they were able to reduce the risk for loss of life from floods (Rana et al., 2021), and the effectiveness of EWS can be measured in terms of lives saved and reduction in losses (Garcia & Fearnley, 2012). An ideal EWS should consist of an operational warning system, end-users, regular testing and modification, monitoring and hazard change detection, collection and analyses, the transmission of the warning message, feedback and all-clear signal warning, and review and re-test system with subsequent modifications (Foster, 1987). An effective EWS is expected to generate information, monitor and forecast hazards, disseminate and communicate information, and enhance response capacity (Damtie & Asmare, 2020; Oktari et al., 2014), and requires effective governance, institutional arrangements, and involvement of local communities and consideration of gender perspective and cultural diversity (Oktari et al., 2014). Furthermore, a good EWS doesn't just analyze data and produce results but also directly communicate the result in an efficient way so that communities can make best use of this information (Rana et al., 2021).

Some researchers carried out studies on early warning systems that have been put into place to prevent and reduce the impact of hazards (Ali et al., 2009; Damtie & Asmare, 2020; Khan et al., 2018; Mustafa et al., 2015; Oktari et al., 2014; Rahayu et al., 2020; Rana et al., 2021). Damtie and Asmare (2020), Oktari et al. (2014), and Rana et al. (2021) evaluated the effectiveness of early warning systems in place from the perspective of experts and community members. Whereas, Mustafa et al. (2015) assessed the gender difference in terms of accessing early warning information.

A study conducted in the Punjab district of Pakistan by Rana et al. (2021) to evaluate the effectiveness of flood EWS indicated that the trust of people in the government's disaster management policies plays a crucial role in their response to disaster warnings. Besides, Damtie and Asmare (2020) added that clear and simple early warning messages enable a proper understanding of warnings and responses to safeguarding lives and livelihoods and stressed that the early warning information should be expressed in non-technical terms and address the six WH questions: when, where, what, how, why, and what to do.

Ali et al. (2009), Chinguwo and Deus (2022), Mustafa et al. (2015), and Rahayu et al. (2020) stated that Community-based Early Warning Systems (CBEWS) have experienced different challenges and have limitations that hinder the system's effectiveness. According to Chinguwo and Deus (2022), Community-based Early Warning Systems in Malawi lack resources and funding, vandalism of river gauges, reliance on donor funding, operational bureaucracy, late warning, inadequate coordination among stakeholders, and deficiencies in the capacity of Civil Protection Committees (CPCs) to interpret and carry out their duties properly are challenges that pose serious threats to the effective running of CBEWS. Similarly, the flood early warning system (EWS) in Golestan lacks written guidelines or procedures for the evaluation and monitoring of its components, cost-effectiveness, and overall effectiveness (Ali et al., 2009).

The finding of studies was varied i.e., in some cases the practice of early warning system was effective in generating risk knowledge, monitoring and warning service, communicating hazards and response capacity whereas others found that the system were ineffective that failed to reduce and mitigate the impacts of hazards. Therefore, this review tried to compile the results of different studies conducted in different parts of the world on early warning systems. As a result, this review will provide information to policymakers, planners, and other interested parties in order for them to act and strengthen early warning systems. This compiled review result will be a basis for understanding the EWSs implemented in various areas. Besides, the review will also add in various ways to the body of knowledge on early warning systems and its major components.

OBJECTIVE AND METHODOLOGY OF THE REVIEW PAPER

The purpose of this paper was to conduct a thorough and critical analysis of early warning systems and information communication with a special emphasis on the significant components of such systems, including risk knowledge, monitoring and warning services, dissemination and communication, and response capacity. The paper aimed to provide clear explanations and insights on these components and synthesize the available information on them.

The literature review approach has been employed to examine research studies focused on early warning systems and information communication. The reviewer conducted a search for articles utilizing the Google Scholar database, resulting in the selection and review of eight articles. These articles were further classified into sections such as risk knowledge, monitoring and warning service, dissemination and communication, and response capacity. In total, five articles were reviewed for each of risk knowledge and response capacity, four for monitoring and warning service, and eight for dissemination and communication.

RESULTS AND DISCUSSION

Risk Knowledge

An effective end-to-end early warning system includes four core elements, which are risk knowledge, monitoring and warning service, warning communication, and response capacity by which each element must function efficiently for the system to be successful (GDPC, 2017). According to WMO (2022), disaster risk knowledge is comprehensive information on all the dimensions of disaster risk, including hazards, exposure, vulnerability, and capacity, related to persons, communities, organizations, and countries and their assets which is gained through the systematic collection of data and disaster risk assessments (ODM, 2023).

According to Damtie and Asmare (2020), the Ethiopian Early Warning System (EWS) has both short-term and long-term objectives, and conducts various assessments, including rainfall, crop, vegetation, livestock, price and market, and food security monitoring. The system has been successful in saving lives during disasters, but the number of affected people is still increasing. The system's focus on prevention, preparedness, and mitigation interventions before disasters has helped reduce the proportion of deaths from disasters, but there is a need to identify the root causes of disasters and initiate developmental activities to eliminate them rather than focusing only on relief efforts and regular monitoring.

The study conducted in Pakistan found that the formal Early Warning System (EWS) is little known among the communities and there is a lack of understanding and ownership over it. Government officials acknowledge the importance of timely and effective EWS, but there is a need for greater integration of gender aspects and citizen-based early warning to enhance the credibility of the institution and its forecasts in the public eye. Additionally, stereotypically, healthy young males are expected to act like heroes and rescue the elders, women and children, securing property and valuables, while women are considered helpless and vulnerable (Mustafa et al. (2015).

According to Damtie and Asmare (2020), the Ethiopian early warning system collects data on potential hazards from each district and kebele on a weekly and monthly basis. However, the system's focus is mainly on hazards, the disaster risk profiling work is incomplete, and the vulnerability and capacity issues are not stated with significant emphasis. In addition to that, there are some problems with the contents of the risk data and there is no organized work on this yet. Besides, Risk maps, outputs of the early warning system that show the spatial distribution and expected losses from one or more hazards, are not commonly used. This finding is consistent with the study conducted by Ali et al. (2009) and Rana et al. (2021) in the Golestan province of Iran and Punjab district of Pakistan respectively. Besides, a study conducted in Ethiopia indicated that *Kebele*[1] lacks responsible experts for disaster risk management, and data collection is managed by other experts who lack knowledge of geological and biological hazards (Damtie & Asmare, 2020).

The study conducted in the Golestan Province of Iran to evaluate the elements of an effective EWS indicated that residents were aware of the risk of flooding but not informed about the hazard map, its components, or its applications and there was no database accessible to the public that contained data on hazard and vulnerability. Despite the efforts of local organizations, it was challenging to obtain a complete understanding of the hazard and vulnerability levels due to the absence of a unified hazard database (Ali et al., 2009). Similarly, even though many people in the Punjab district of Pakistan had a high understanding of the national warning system for floods, this was not the case in Rawalpindi city where only a small number of households had a high understanding. This lack of understanding could prevent people from responding to flood warnings, even if the warning system is fully functional (Rana et al., 2021). Therefore, it is important to improve local awareness of the warning system and regularly assess the level of understanding to ensure that people take the warnings seriously.

In contrast to the above, according to the study conducted in Malawi, communities are aware of the risks of floods in their areas, and each district has a hazard map that identifies flood-prone areas. Some communities have inter-village or inter-district alliances to share information on floods, and some even use local observations, such as the movement of ants or hippos, to predict

[1] The lowest administrative unit in Ethiopia

the possibility of flooding. It was found that people living in the affected areas within the district are aware of the hazards and vulnerabilities, and in areas where floods occur annually, the communities are familiar with the dynamics of the hazard, and evacuation plans and routes are known to all due to periodic meetings community leaders held to update and sensitize communities to weather patterns (Chinguwo & Deus, 2022).

Monitoring and Warning Service

Early warning systems are key elements of climate change adaptation and disaster risk reduction and aim to avoid or reduce the damages caused by hazards (Climate ADAPT, 2022), and monitoring and warning service is one of the major components of early warning system (UNISDR, 2009). Different scholars such as Ali et al. (2009), Chinguwo and Deus (2022), Damtie and Asmare (2020), and Mustafa et al. (2015) assessed the practice of monitoring and warning services in early warning systems in their studies.

According to Mustafa et al. (2015) in the Lai basin of Pakistan, most communities were unaware of the formal EWS operating in their area and it is found to be unreliable and inaccessible to the communities living along the river banks. The community largely relies on its vigilance as an early warning system. People living along the Lai basin in Pakistan rely on their own observations of weather, precipitation, and flow conditions to predict the severity of floods. Besides, mosques, television announcements, and cell phone calls from relatives were sources of flood warnings, while women, particularly those in the Christian minority, had limited access to information due to gendered roles (Mustafa et al., 2015).

The Ethiopian Early Warning System is designed to assess all potential hazards; however, it is less effective due to the diverse characteristics of hazards. It mainly collects stress and late indicators, which are crucial for response and recovery works but not for pre-disaster risk management interventions. The system is not flexible enough to detect new hazards, as they are usually only recognized after they have occurred. Additionally, the baseline of the system is problematic, as it has not been updated since 2005, and the early warning system relies on visual observation and expert reports which lack national standards and measurements. Information from the national meteorology agency is not timely, detailed enough, or trustworthy, and even though the system is effective for slow-onset hazards but not for rapid-onset hazards, and there are limitations in monitoring and warning about certain types of disasters (Damtie & Asmare, 2020).

Chinguwo and Deus (2022) also added that in Malawi there are two flood warning systems: one at the national level managed by DCCMS and DWR, and one at the community level managed by CPC with the help of NGOs or developmental partners. However, there is no direct linkage between the two systems, leading to bureaucracy in getting messages across, and the community-based systems are sponsored by NGOs or churches and tied to projects, which have a limited lifespan and are prone to vandalism. Besides, Local communities in the district lack the technical expertise to monitor hazards and only use river gauges to monitor water levels. The Ministry of Agriculture, the DWR, and the DCCMS have installed weather monitoring stations to monitor weather patterns, but there is no direct link between these tools and the Community-Based Early Warning Systems (CBEWS) (Chinguwo & Deus, 2022).

Flood hazard monitoring and warning in the Golestan province of Iran is done by the province's Meteorological Office (MO) which obtains data from the State Meteorological Organization (SMO). The Provincial Disaster Taskforce faces challenges in issuing early flash flood warnings due lack of ability to make point predictions of rainfall and estimate the probability of flood occurrence at a specific level of precipitation (Ali et al., 2009).

Dissemination and Communication

To maintain and strengthen the existing EWS and achieve sustainable development, evaluation of EWS effectiveness is important to identify the current situation, improve EWS effectiveness, make priorities and action plans, and evaluate performance (Oktari et al., 2014), and according to Rana et al. (2021), the success of disaster-related warnings depends not only on the credibility of the Early Warning System but also on the medium used to communicate the warnings to the community.

According to the study conducted by Oktari et al. (2014) on effectiveness of dissemination and communication element of tsunami early warning system in Aceh revealed that the system have several shortcomings. The Standard Operational Procedure (SOP), which provide practical guidance, step by step description of tasks to be effectively performed by each actor that involved in crisis situation, was not well socialized, lack of involvement from other institutions in the warning dissemination chain, the media, and private sector were not actively involved, and there was a lack of various communication modes, backup systems, and regular testing. Additionally, there was no two-way communication system to verify message receipt and no proper mechanism to inform the community when the threat had ended. There was still a lack of public education for media, public officials, and the community, and no evaluation had been conducted on how the community perceived and understood the warning messages they received. Generally, the dissemination and communication of tsunami EWS in Aceh have progressed, but systematic policy and/or institutional commitment did not exist.

Similarly, a survey conducted in the State of Azad Jammu & Kashmir of Pakistan at high risk of flash flooding showed that the existing early warning system (EWS) lacked accessibility and effectiveness in issuing timely warnings to vulnerable communities. The study shows the majority of people were not informed about potential threats during past flooding events (Khan et al., 2018). This implies the need for developing a community-friendly EWS that meets community expectations.

Another study conducted in Golestan province also indicated that incomplete technical understanding by other organizations, absence of clear regional demarcations, operational inefficiency, poor comprehension of technical terms in rural areas, and failure of target organizations to act on warnings in a timely fashion are identified as limitations in the communication warning related to flash floods. These factors contribute to inadequate communication with the public and low overall efficiency of the province's dissemination and communication system. Besides, communication follows a top-to-bottom direction and the contents are not clearly understood by communities and institutions effectively which hinders reaching their intended recipients. In addition to that, although the Golestan MO can predict heavy rainfall, their inability to determine the probability and precise location of flash floods has made communities indifferent towards warning messages, and the time it takes for a warning message to reach flood-prone communities is too long compared to the lead-time for flash floods (Ali et al., 2009).

In addition to that according to the study conducted by Damtie and Asmare (2020) in the Dera and Jabithenana district of Ethiopia, many households lack access to early warning information, and the early warning system lacks important information on vulnerability and the reasons behind it. Besides, the quality of early warning information is also affected by subjectivity and external influences, such as political leaders, which can have a significant impact on response provision for vulnerable communities, particularly during food insecurity problems. The researchers added that the main sources of warning information are government-employed experts, radio, and television, and the non-availability of electronic equipment makes communication difficult. Similarly, the study conducted in Pakistan found that the Early Warning System (EWS) faces challenges due to a lack of communication with some households and a failure of communities to follow the right procedures even when they receive warnings (Rana et al., 2021). This could be due to their inability to understand the severity of the warnings or distrust of the local government.

The Tsunami early warning system in the Padang City of Indonesia, community health centers, police, public works agency, development planning agency, social agency, and others are organizations responsible for these functions. Besides, NGOs and civil society organizations, such as the Red Cross and tsunami preparedness community also act as an interface between the city level and the community for tsunami early warning dissemination and community leaders to the last-mile communities, and various communication devices including tsunami sirens activated by Padang City EOC, access to mainstream media such as TV and radio channels, and other telecommunication devices with their links or acquaintances in the civil institutions are used for dissemination of tsunami warnings to the last-mile community, with community leaders playing a significant role. The rest rely on warnings from local mid-actors or community leaders. Besides, the study identified four interface actors in the community, including sub-district offices, schools, community mosques, and disaster preparedness community groups, which have different potential roles in the warning chain (Rahayu et al., 2020). This implies the involvement and empowerment of community leaders were found to be highly advantageous, not only for the warning dissemination process but also for other types of sudden onset hazards.

Chinguwo and Deus (2022) also found that there is a mechanism for disseminating and communicating flood-related information in Malawi, with CPCs having periodic meetings and various means of communication such as whistles, community radio, megaphones, drums, color flags, and word of mouth which serves as a mechanism for disseminating and communicating vital information. However, the bureaucratic nature of the system can lead to delayed information and generalized warning messages that are not area-specific, leading to people not taking them seriously. Similarly, according to Ali et al. (2009), the Meteorological Office in Golestan province uses written documents to issue early warnings of flash floods. and in Punjab of Pakistan, television, telephone, radio, and newspapers were the most preferred sources of communication for flood warnings, while social media was the least preferred due to limited access and trust issues, and in emergencies, urgent alarms are communicated by phone or in person (Rana et al., 2021).

According to Rana et al. (2021), in flood-prone communities in Punjab, Pakistan, most households in Rawalpindi did not receive any warning about previous floods, while it is better in Sialkot and Muzaffargarh. This suggests that the effectiveness of the early warning system (EWS) varies across different areas. Researchers identified five different channels used to communicate flood warnings in the communities studied, including District Authority, Local Authority, Police, Mosque, and Army. However, no single source of communication was identified as an efficient means for issuing flood warnings. These authors described those households and local officials in flood-prone areas lack awareness about the high flood risk in their locality, indicating poor risk communication and perception. Due to the ineffective local government, the community's trust has been lost, leading to skepticism about the early warning system (EWS). Besides, the system is designed in a top-to-bottom manner with little input from local communities. As a remedial measure, communities choose volunteers to safeguard embankments, indicating the need for improved risk perception and communication in exposed communities.

In addition to the above studies, Mustafa et al. (2015) studied the gender aspects of the early warning system in the Lai basin of Pakistan and found that women are often caregivers and have limited access to external sources of information, making it difficult for them to receive flood warnings. Language barriers and strict cultural norms further restrict their ability to access information and respond effectively to hazards, leading to women relying on men to receive hazard information indirectly.

Response Capacity

Disaster risk reduction (DRR) emphasizes preparedness-driven approaches over relief, and an Early Warning System (EWS) is a major component of disaster preparedness. Effective forecasting, timely conveyance, and response mechanisms are crucial for good EWS (Rana et al., 2021). The final goal of an early warning system is to create effective hazard responses, which requires knowledge of risk management and the involvement of knowledgeable community members (Damtie & Asmare, 2020). However, many studies indicated that early warning systems face challenges and have limitations in providing sufficient and appropriate responses (Ali et al., 2009; Chinguwo & Deus, 2022; Damtie & Asmare, 2020; Mustafa et al., 2015; Rana et al., 2021). According to the study conducted by Mustafa et al. (2015) in Pakistan, 69.3% of respondents were prepared to respond to hazards, but the cost-effectiveness of responses was also a concern. The authors identified the shortcoming of the EWS particularly in terms of being people-centered and gender-sensitive. They found that people's response to flood warnings is influenced by gender roles and stereotypes, with women often taking on the responsibility of protecting their families and securing food and shelter. Men may feel pressure to rescue their families and secure their livelihoods and reveal the existence of self-organized responses, such as building floodgates and moving belongings to higher ground. In addition, another challenge is false alarms in meteorological information that led the communities to reluctance to heed warnings.

Similarly, the study conducted in Ethiopia to evaluate the early warning system, particularly in Dera and Jabithenana districts indicated that the Ethiopian early warning system faces challenges in providing sufficient and appropriate responses, particularly for small-scale hazards that affect specific groups of people. Besides, staff capacity, generic approach, late and stress indicators, lack of attention to all risk factors, and inadequate response plans are other problems identified. The system also lacks accessibility and understanding for all people at risk, and the food aid response is insufficient. To be effective, the system needs to address these problems and manage them (Damtie & Asmare, 2020). Besides, according to Rana et al. (2021), low literacy in vulnerable communities hinders their ability to understand and adhere to emergency protocols.

Another study conducted by Chinguwo and Deus (2022) in Malawi found that to improve the response capability of the community-based early warning system and reduce the impact of flooding, guidelines have been established at national, district, or community levels, and periodic meetings are held between Civil Protection Committees (CPCs) to strategize, remind and reaffirm each other of response plans, evacuation plans, and evacuation areas in case of a flood. The Disaster Risk Management Operational Guidelines mandate local authorities to ensure that their communities are capable of responding to disasters by developing multi-hazard contingency plans, evacuation plans, and recovery plans in line with national plans. In flood-prone areas, periodic meetings are held to remind community members of what is expected of them during a disaster, and safe havens such as school grounds, places of worship, and nearby hills have been identified. Drills are also carried out to simulate flood disasters and test the community's response rate.

In contrast to the above, according to Ali et al. (2009), there are no preparedness and response plans for flash floods in the Golestan province. There are no documented guidelines or drills for responding to flash floods, and the residents' reaction to such events is based solely on experience. The absence of reliable hazard maps and the inability to determine the location of flash floods make it impossible to define the exact scope of any response operations. These scholars added that the main challenge faced by the local government in flood-prone areas is to evacuate people from their homes, even when early warning systems are in place. Officials have tried to use SMS alerts to communicate with people but with little success. Another issue is the lack of communication and coordination between different departments and tiers of government, which can hinder effective disaster management. Besides, The National and Provincial governments in Pakistan have different priorities, such as energy crisis, poverty, and terrorism, which can sometimes conflict with the goals of effective disaster management. To overcome these challenges, stronger liaison and coordination between different government agencies is needed.

Better early warning mechanisms are needed to allow for timely and appropriate action and considering the different vulnerabilities, needs, and resilience of vulnerable populations, as influenced by socio-economic resources, gender, ethnicity, age, and location are important (Mustafa et al., 2015). Community involvement is essential for the success of the overall system, and two-way communication is needed to ensure that recipients react to the warnings (Rana et al., 2021).

CONCLUSION AND RECOMMENDATIONS

An efficient EWS should consider the risks faced by the exposed communities and incorporate short-term or long-term mitigation measures, and the effectiveness of EWS can be measured in terms of lives saved and reduction in losses, and an effective end-to-end early warning system includes four core elements, which are risk knowledge, monitoring and warning service, warning communication, and response capacity by which each element must function efficiently for the system to be successful. However, the EWSs are still limited in their ability to save life and properties through forecast all types of hazards. Therefore, the purpose of this paper was to review studies conducted on early warning systems.

Disaster risk knowledge is comprehensive information on all the dimensions of disaster risk, including hazards, exposure, vulnerability, and capacity, related to persons, communities, organizations, and countries and their assets which is gained through the systematic collection of data and disaster risk assessments. However, the formal Early Warning System is little known among the communities and there is a lack of understanding and ownership over it. In most cases, the communities are not informed about the hazard map, its components, or its applications and there was no database accessible to the public that contained data on hazard and vulnerability.
Monitoring and warning service is one of the major components of early warning system. It is found to be unreliable and inaccessible to the communities, and mostly the communities rely on

their own observations of weather, precipitation, and flow conditions to predict the severity of floods. Besides, absence of direct linkage between the formal and informal warning systems leading to bureaucracy in getting messages. Moreover, Local communities lack the technical expertise to monitor hazards.

The credibility of the Early Warning System but also on the medium used to communicate the warnings to the community. Dissemination and communication component of early warning systems in different countries have several shortcomings. There was no two-way communication system to verify message receipt and no proper mechanism to inform the community when the threat had ended, and the contents are not clearly understood by communities and institutions. Besides, the quality of early warning information is also affected by subjectivity and external influences, such as political leaders, which can have a significant impact on response provision for vulnerable communities. Accordingly, the main sources of warning information are government-employed experts, radio, television, periodic meetings, whistles, community radio, megaphones, drums, color flags, and word of mouth. However, the bureaucratic nature of the system can lead to delayed information. Moreover, women are often caregivers and have limited access to external sources of information, making it difficult for them to receive warning information.

In regard to response capacity, the early warning system faces challenges in providing sufficient and appropriate responses, particularly for small-scale hazards that affect specific groups of people. Besides, staff capacity, generic approach, late and stress indicators, lack of attention to all risk factors, and inadequate response plans are other problems identified. Another issue is the lack of communication and coordination between different departments and tiers of government, which can hinder effective disaster management.

Therefore, better early warning mechanisms are needed to allow for timely and appropriate action and considering the different vulnerabilities, needs, and resilience of vulnerable populations, as influenced by socio-economic resources, gender, ethnicity, age, and location are important, and community involvement is essential for the success of the overall system, and two-way communication is needed to ensure that recipients react to the warnings. Besides, Disaster management institutions should focus on using credible and efficient means of announcement to build trust in the community and increase awareness about EWS, and they should focus on the medium of information dissemination which is accessible to the community. In addition to that, institutions should employ multi-disciplinary professionals, such as graduates of disaster risk management and sustainable development, and provide short and long-term training to strengthen the quality and specialization of experts.

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Effect of the Genotype by Environment Interaction on the Productive and Reproductive Performance of Livestock in Ethiopia: A Reviews

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Abstract:
The review was undertaken with the aim of assessing the effect of genotype-environment interaction (GEI) on the productive and reproductive performance of livestock across tropical countries, including Ethiopia. This review is based on published scientific research investigating the effects of genotype-environmental interaction on the productive and reproductive performance of selected livestock species in tropical countries. Genetic correlation and heritability estimates were assessed as indicators for the presence of GEI for traits among the environments. Spearman's ranking correlation was also assessed as a means for appropriate sire re-ranking for selection. According to the reviews, significant GEI was observed over productive milk traits such as lactation milk yield, initial milk yield, and average milk yield. Similarly, a significant GEI effect was also observed in the body weight gain performance of livestock in Ethiopia and other tropical countries. Reproductive traits such as age at first service, service period, and age at first lambing were also affected by GEI. The chicken egg traits such as shell thickness, egg weight, egg width, and egg length were also affected by the differences in environments and management conditions. The influence of GEI on the phenotypic expression of traits among environments was assessed based on assumptions indicating that GEI has significant importance if the genetic correlation of traits between environments is less than 0.80. General, genetic correlation, and heritability estimates in the tropics showed significant GEI for the productive and reproductive performance of animals, and hence the genetic evaluation and selection of sires require information from both locations to accurately select the most appropriate sire for each location.

Keywords: GEI, genetic correlation, heritability, traits

INTRODUCTION

The interaction of genotype by environment (GEI) refers to the different responses of genotypes to different environmental conditions. It also explains the change in the relative performance of two or more genotypes measured in two or more environments (Wakchaure et al., 2016). Understanding the genotype through environmental interaction is crucial for developing appropriate breeding and management strategies that best suit a specific environmental management setting. By identifying the most suitable genotypes for different environments, livestock producers can optimize productivity and reproductive performance, ultimately contributing to the sustainable development of the livestock. Rashid et al. (2016) stated that the most important thing in the field of animal breeding is mostly associated with identifying and developing genotypes that provide continuous economic performance under varied production. Most importantly, understanding the opportunities and limitations of the production environment where animals are maintained provides an important basis for sustainable livestock intensification and the appropriate use of livestock genetic resources (Ashebir et al., 2014). This is mostly associated with the fact that the expression of inherited genetic merit varies across environmental conditions and is greatly influenced by non-genetic factors (Dal et al., 2003). Usman et al. (2013) stated that the full expression of the genetic worth of animals depends on the extent of genotype and environmental interaction. Hence, it needs the appropriate quantification of GEI for maximizing yield from livestock (Paula et al., 2009). Williams et al. (2012), in line with these results, mentioned that the appropriate knowledge of GEI helps livestock producers select the best animals that are proven to have the best performance. Usman et al. (2013) state that animals perform well in their natural home. Their work further reported that 30–40% milk yield reduction temperate dairy cattle breeds evaluated in the tropics. Appropriate quantification of GEI can improve artificial selection progress and increase the efficiency of genetic evaluation of sires that are managed under different environmental conditions (Guidolin et al., 2012).

Scholars have used different approaches to know the presence of an estimate GEI. The basic approach was associated with estimating the genetic correlation between phenotypes for given traits under different environmental conditions (Wakchaure et al., 2016). Many studies indicated that estimating genetic correlations between or among environments has been mostly used to indicate the influence of GEI on the expression of phenotypic performance of traits (Ashebir et al., 2014; Rashid et al., 2016; Wakchaure et al., 2016). A high GEI variance component will result in a low (Kang, 2002), which could also mean assessing the influence of GEI.

Earlier studies have reported the existence of significant GEI in different productive and reproductive traits. Rashid et al. (2016) reported the presence of large effects of GEI on the growth traits of Brahman crossbred cattle kept on station and in farm conditions. This interaction has become a critical component in livestock production due to producers selecting sires for improved performance, which is not being observed in the performance of the offspring (Wakchaure et al., 2016). Therefore, it is important to understand the production environment while making management decisions, such as selecting breeds in a crossbreeding system, since interactions may influence reproductive efficiency.

In the absence of GEI, the expected genetic correlation across environments is one. Greater than 0.80 genetic correlations between environments do not show evidence for strong GEI (Wakchaure et al., 2016). A large genetic correlation of traits between environments indicates a slight GEI effect, whereas a small genetic correlation between traits indicates a strong GEI influence on the phenotypic performance of animals. A long-term study by Robertson (1959) reported that serious reductions in the efficiency of animal breeding programs may occur when the genetic correlation between environments is lower than 0.8. Low genetic correlations were obtained between countries that differ considerably in climate, management, and production systems.

In tropical countries with diverse agro-ecological conditions and livestock management practices, the performance of genotypes may differ substantially across the range of available environmental conditions (Ashebir et al., 2014). Kolmodin and Bijma (2004) reported that the phenotypic expression of a trait in different environments would be determined by different sets of genes that are differently expressed under different environments and management conditions. The variation of genotype in different environments is attributed to factors such as climate, feed resource availability, prevalence of disease, and other associated variables. It can be evident that tropical countries, including Ethiopia, are endowed with varied agro-ecological zones where the performance of different livestock genotypes can vary significantly within the specific agro-ecological zones. This variation is attributed to factors such as climate, feed availability, disease prevalence, and other environmental variables. Therefore, based on the above background facts, current reviews assess the effects of genotype and environmental interaction on the productive and reproductive performance of selected livestock species (cattle, sheep, and poultry) in tropical countries, including Ethiopia.

LITERATURE REVIEWS

Genotype by Environmental Interaction

A genotype by environment interaction is manifested when genotypes (individuals, lines, varieties, breeds, etc.) show a differential phenotypic response across one or more environments. Stated differently, an interaction occurs when yield/product gains made in a particular environment are not transferred to another environment. The presence of a genotype by environment interaction with widely divergent genotypes and environments is well known and documented in both plants and animals. Studies of genotype x environment interactions are becoming more important as cattle genotypes are now being managed in a diverse range of environments (Bryant *et al*., 2005). Furthermore, Dominik *et al*. (2001) postulate that different genetic relationships exist between different traits across environments. This is supported by different genetic correlations for milk, fat and protein in the high and low yield environments in dairy cattle reported by Castillo-Juarez *et al*. (2002).

Genotype by environment interaction (GEI) could be defined as a change in the relative performance of two or more genotypes measured in two or more environments (Ashebir *et al*, 2014). The G×E means simply that the effect of the environment on different breeds or genotypes is not the same which implies there is no universally best genotype (Rashid et al., 2016). The authors reported that the performance of best genotype vary from one environment to other. The performance of best genotype depends on prevailing environment condition which needs genotype by environment interaction should be considered.

In the presence of GEI interaction, the expression of phenotypic traits in different environment is/are determined by different set of the genes (Kolmodin and Bijma, 2004). Under condition like this, the breeding goal should account for both traits and environment under which these traits would be expressed (Ashebir *et al*., 2014). GEI interaction may result in heterogeneity of genetic variances across environments which alter ranking series of genotype between environments (Callus, 2006). Genotype by environmental interaction that alters the ranking of series of genotypes between environments could considerably hamper selection.

Effects of Genotype by Environment Different Livestock

Estimation of Genotype by Environment Interaction for Cattle Milk Traits:

Genotype by environmental interaction has been reported for the association of milk traits such as protein, fat yield, and somatic cell score (Raffrenato et al., 2003), milk yield with fitness traits (Beerda et al., 2007), and milk yield with age at first calving (Ruiz-Sánchez et al., 2007). A recent study conducted in Ethiopia also observed a significant influence of GEI over milk production traits in Bako and Holetta, Ethiopia (Ashebir et al., 2014). The influence of GEI on cattle milk traits in Ethiopia is presented in Table 1.

According to the result for GEI, Holstein Friesian (HF) crossed cows had a higher least mean square (LSM) for milk traits such as lactation milk yield, initial milk yield, peak milk yield, and average milk yield than Simmental and Jersey crossed cows at Holetta. Similarly, the LSM value of the HF-crossed cow at Holetta was higher as compared with the same LSM value for the HF, Jersey, and

Simmental-crossed cow at Bako for milk production traits involved. However, there was no significant difference observed for traits (all) between Jersey and Simmental crossed cows at Holetta ($p<0.05$). Indigenous cattle breeds such as Boran and Horro didn't have significant effect of GEI over milk production considered at $p<0.05$ in Holetta and Bako area.

According to Ashebir et al. (2014), the observed significant difference between indigenous and crossed cows for traits was due to the large genetic difference between additive genetic effects introduced and non-additional genetic effects generated by crossbreeding. The issue of GEI arises when the performance of different genotypes is not equally influenced by different environments, such as climatic and management differences at Holetta and Bako, as indicated by Ashebir et al. (2014).

Table 1: Least square mean ± standard errors for GEI of selected milk production traits in Holetta and Bako

GEI	LMY (kg)	IMY (kg)	PMY (kg)	AMY (kg)
Bako –B	965.57 ±38[d]	2.17±0.49[e]	3.60±0.51[g]	2.34±0.33[e]
Bako –H	1172.68±33.97d	2.87±0.15[e]	4.73±0.16[fg]	2.68±0.10[e]
Bako –FXB	1703.21±25.06[b]	6.03±0.21[c]	8.64±0.12c	5.19±0.08[c]
Bako –JXB	1575.06±26.06[c]	5.54±0.12[cd]	7.89±0.13[d]	4.81±0.08[d]
Bako - SXB	1725.06±38.50[b]	6.00±0.18[c]	8.75±0.18[c]	5.29±0.12[bc]
Holetta – B	1369.72±76.75[cd]	4.72±0.35[d]	6.99±0.37[de]	3.49±0.24[e]
Holetta – H	1205.88±96.65[d]	4.17±0.44[de]	6.11±0.46[ef]	2.86±0.30[e]
Holetta – FXB	2111.91±16.88[a]	9.26±0.08[a]	11.64±0.08[a]	6.57±0.05[a]
Holetta – JXB	1793.11±22.91[b]	7.83±0.11[b]	9.96±0.11[b]	5.60±0.07[b]
Holetta – SXB	1807.03±34.17[b]	7.79±0.16[b]	10.35±0.16[b]	5.72±0.11[b]

Superscript for least square mean with different letter ([a,b,c,d,e,f,g]) are significantly different ($P<0.0001$). GEI – Genotype by Environment Interaction, LMY stands for lactation milk yield, IMY stands for initial milk yield, PMY stands for peak milk yield and AMY stands for average milk yield. B stands for Borana cattle breed, H stands for Horro cattle breed, FXB stands for Friesian crossbred, JXB stands for Jersey crossbreed and SXB stands for Simmental crossbreed.

Variance components such as sire additive genetic variance, permanent environmental variance, residual variance, and phenotypic variances were estimated for milk production traits under Holetta and Bako (Table 2). The larger sire additive genetic variance was for all traits except lactation yield at Bako than at Holetta (Ashebir et al., 2014). On the other hand, lower permanent environmental variances, residual variances, and phenotypic variances were observed for all traits at Bako than at Holetta.

Heritability estimates in relation to the environment were conducted by different researchers in different areas (Gebreyohannes et al., 2013; Sofla et al., 2011; Ojango and Pollott, 2002). A study conducted in Ethiopia by Gebregziabher et al. (2014) estimated lower heritable values for cattle breeds reared in Bako and Holetta research stations for milk production traits (Table 3). The relatively higher heritability value estimated at Bako than Holetta was largely due to higher permanent environmental variances (Table 2, lactation milk yield 66,554.2 kg2 at Bako vs. 125,166 kg2 at Holetta) at Holetta than Bako. The study conducted on the same cattle population by Gebreyohannes et al. (2013) using a single trait repeatability animal model and a combined dataset from the same population showed the heritable estimate for lactation milk yield was 0.36.

The report of the previous result showing a lower heritable value at Holetta than Bako suggests the higher production (for example, milk yield difference) was probably due to a greater extent of favorable environmental conditions than genetic differences among sires. The study conducted on Holstein cattle in Iran reported the heritable estimate was 0.28 and 0.30 over Holstein cattle reared in dry desert and semi-dry desert, respectively. The areas represent less favorable climates, but the values were similar or higher than the heritable estimate under more favorable climates (Sofla et al., 2011). Comparative studies focused on the milk yield performance of Holstein showed a higher milk yield in the UK than in Kenya (Ojango and Pollott, 2002). The heritability estimate for first lactation based on 305-day milk yield was higher in the UK (0.45) than in Kenya, according to the report by Ojango and Pollott (2002). The result suggested a combination of lower adaptability and lower feed intake under tropical conditions (Kenya), which would be otherwise different under the temperate conditions where Holstein originated.

Table 2: Variance components for lactation pattern and milk production traits at Bako and Holetta

Location	Traits				
	Variance	Lactation milk yield (kg^2)	Initial milk yield (kg^2)	Peak milk yield (kg^2)	Average milk yield (kg^2)
Bako					
	σs^2	14,446.5	0.33	0.37	0.19
	σpe^2	66,544.20	1.15	2.07	0.78
	σe^2	118,158.00	3.36	2.98	1.28
	σp^2	199,148.70	4.83	5.41	2.25
Holetta					
	σs^2	18,681.10	0.24	0.33	0.17
	σpe^2	125,166.00	1.95	2.30	1.10
	σe^2	142,012.00	4.19	3.47	1.41
	σp^2	285,859.10	6.38	6.11	2.68

σs^2 – sire additive genetic variance, σpe^2 – permanent environmental variance, σe^2 – residual variance and σp^2 – phenotypic variance

Table 3: The estimated heritability (h^2) of lactation patterns and milk production traits at Bako and Holetta, Ethiopia (adopted from Gebregziabher et al., 2014).

Traits	Heritability	
	Bako	Holetta
Lactation milk yield (kg)	0.29 ± 0.12	0.26 ± 0.08
Initial milk yield (kg)	0.27 ± 0.11	0.15 ± 0.06
Peak milk yield (kg)	0.27 ± 0.01	0.22 ± 0.01
Average milk yield per day (kg)	0.34 ± 0.13	0.26 ± 0.08

The genetic correlation across environments in the absence of GEI is expected to be one (Ashebir et al., 2014). The genetic correlation value is significantly less than one, which indicates the presence of GEI. Under this condition, GEI needs to be considered in the genetic statistical model used for the genetic evaluation and selection of animals.

In the study conducted by Ashebir et al. (2014), the genetic correlation between Bako and Holetta for lactation milk yield, initial milk, and average milk yield was estimated to be 0.82, 0.53, and 0.62, suggesting GEI between these two locations. The result of the authors was in agreement with the genetic correlation value (0.78) of milk yield obtained from the Jersey cattle population of South Africa for the locations between Drier Overberg and the South Cape region versus Subtropical Limpopo and Northern KwaZulu-Natal (Van Niekerk et al., 2006). A similar genetic correlation estimate (0.80) was also reported by Nauta et al. (2006) between a conventional production system and an organic production system, which also indicates the presence of GEI for milk yield. A study conducted in Canada by Boettcher et al. (2003) estimated a genetic correlation (0.93 ± 0.04) for milk yield for herds managed between intensive rotational grazing and conventional grazing involving stored feed, suggesting minor GEI effects for milk yield. A previous study conducted in Ethiopia by Ashebir et al. (2014) indicated the difference in climate and feeding management over Bako and Holetta was responsible for lower genetic correlation for traits as compared with the higher genetic correlation estimate observed in Canada by Boettcher et al. (2005), where the difference seems minimal.

Table 4: The estimate of genetic correlation of different traits between environments Bako and Holetta

Traits	Trait's type	GC	Location	Sources
LMY (kg)	Milk traits	0.82 ± 0.32	Bako vs. Holetta, Ethiopia	Ashebir *et al*. (2014)
IMY (kg)	Milk traits	0.53 ± 0.39	Bako vs. Holetta, Ethiopia	Ashebir *et al*. (2014)
AMY (kg)	Milk traits	0.61 ± 0.33	Bako vs. Holetta, Ethiopia	Ashebir *et al*. (2014)
AMY (kg)	Milk traits	0.93± 0.04	Intensive vs. conventional management, Canada	Boettcher *et al*. (2003)
LMY (kg)	Milk traits		Humid vs. dry climate, Iran	(Wakchaure *et al*. (2016)
	-	0.49	USA vs. Kenya	(Ojango and Pollot (2002)

*p<0.0001, LMY – stands for lactation milk yield, IMY stands for initial milk yield and AMY stands for average milk yield.

The spearman correlation can be used to indicate the presence of GEI across the location. It reflects the difference in environmental condition across locations which can be used for re-ranking of breeding sires considering their breeding values between the locations. The spearman correlation value between Holetta and Bako areas for lactation milk yield, initial milk yield, and average milk yield ranged between 0.86 and 0.87 (Table 4; Ashebir et al., 2014). Generally, GEI observed based on genetic correlation as well as Spearman's rank correlations between sire predicted breeding values across locations suggested that genetic evaluation and selection of sires would require information from both locations to accurately select the most appropriate sires for each location.

Estimation of Genotype by Environment Interaction for Cattle Growth Traits:

The study was conducted to evaluate the effects of genotype-environment interaction on the growth traits of Brahman crossbred cattle raised in intensive versus semi-intensive systems in Bangladesh (Rashid et al., 2016). The authors observed GEI influence for growth traits. The genetic correlation was estimated between three months and two to 24 months. According to the result, there was a decreasing trend for genetic correlation as the age of the animal increased, indicating a higher GEI influence for older animals as compared with younger animals. The trend of genetic correlation over the development stage is presented in Table 5. The genetic correlation obtained on the growth traits of Brahman crossed cattle was within the range of agricultural and biological importance. The decision was made based on long-term research by Robertson (1959) suggesting that GEI should be considered when genetic correlations were less than 0.8.

The result of Assenza et al. (2010) was in agreement with the result of Rashid et al. (2016), indicating the existence of significant GEI for yearling weight and growth during the post-weaning period in Creole cattle fattened under two contrasting environments, and the authors measured the reduced genetic correlation as the age of the animal increased. The estimated genetic correlation of Nellore cattle reared in feedlots and on pasture on final weight was reported to be 0.75 (Raidan et al., 2015). On the other hand, Beffa et al. (2009) observed a high genetic correlation estimate (0.96) for different growth traits across different management environments.

Table 5: The genetic correlation for growth traits of Brahman crossed cattle in Bangladesh.

Age (months)	3MW	6MW	9MW	12MW	18MW	24MW*
Genetic correlation	0.74	0.72	0.72	0.64	0.53	0.57

*MW- Month Weight

Genotype by Environmental Interaction for Chicken Production Traits:

A previous study (Abebe et al., 2009) conducted in Southern Ethiopia evaluated the productive performance of two chicken breeds—Rhode Island Red and Fayoumi—that were kept under two management systems—on station and on farm at different ages, and the results were compared with local chickens owned by farmers. The result of the study showed that significant breed-environment interaction was observed for all the traits (egg production, egg quality, body weight, feed conversion efficiency) measured in both systems. Accordingly, Fayoumi chicken provided more eggs than Rhode Island Red in both environments. Similarly, Fayoumi chicken had higher feed conversion efficiency than Rhode Island Red. On the other hand, Rhode Island had a higher value for egg quality traits and gained more weight than Fayoumi. Moreover, chickens kept on the farm (local chickens compared) had poorer performance than those at the station for almost all traits except yolk color.

Another recent study by Kejela et al. (2019) was conducted with the objective of analyzing egg quality parameters of chickens (local, Sasso, and Bovans brown) reared in Hawassa and Yirgalem towns, southern Ethiopia. The study reported a high egg weight variation between genotype and environment for three categories of chickens (Table 3). The egg quality-related parameters studied by Kejela et al. (2019) included egg weight, egg length, egg width, dry shell weight, and shell thickness.

Egg Weight:

A previous study by Gezahegn et al. (2016) reported that the size and weight of eggs are moderately heritable traits that are influenced by genotype and environmental interaction. Recent research results (Kejela et al., 2019) and research conducted in the Oromiya region (Tadesse, 2012, and Tadesse et al., 2015) reported that eggs obtained from Sasso and Bowans brown chickens had a higher weight than the local chickens studied.

The result Kejela et al. (2019) showed that there was no significant weight difference between Sasso and Bowan brown in Hawassa town, which was on the other hand shown in Yirgalem town, where Bown brown had a higher egg weight performance than the Sasso chicken breed ($P<0.05$). The result of the current study was in agreement with other findings from Ethiopia (Emebet, 2015; Aberra et al., 2012; and Molla, 2010). Another study by Zita et al. (2009) reported the presence of a correlation among the genotype of chickens, their weight, and their eggs. The other research work also reported that the age of the chicken and the weight of its egg are correlated in line with the quality and availability of feed the chicken is given; better quality feed availability caused the chicken to lay a relatively heavy egg (Padhi et al., 2013).

Shell Thickness:
Shell thickness constitutes external egg quality and can be defined as a measure of the shell strength of an egg associated with reduced eggshell breakage (Alewi et al., 2012). There have been a number of reports on egg shell thickness in different parts of the world. Research work from an on-station experiment over naked-neck chicken in Ethiopia reported the value of egg shell thickness being 0.370 mm (Melese et al., 2010). The higher comparative value (0.580 mm) on egg shell thickness was reported by Fayye et al. (2005) in their research work conducted on the scavenging Fulani ecotype of Nigeria. This variation in egg shell thickness in different regions could be associated with the quality, quantity, and nutrition composition of the available feeds for chickens (Abera et al., 2012).

A similar result on shell thickness was reported by Kejela et al. (2019) over three chicken types studied in Hawassa and Yirgalem towns in southern Ethiopia. The author (s) reported average egg shell thickness values (mm) of 0.22, 0.25, and 0.28 for local, Sasso, and Bowans Brown chickens, respectively. The result showed significant genotype-environment interaction in terms of egg shell thickness across two locations. The higher egg shell thickness value was observed for Sasso chicken in Hawassa town than in Yirgalem town. In contrast, the egg shell thickness of Bovans Brown chicken had a higher value in Yirgalem town than Hawassa. Abera et al. (2012) reported that the overall shell thickness of indigenous chickens under different agro ecologies in the Amhara Region was 0.309 mm. Other finding in the Jimma Zone of Ethiopia reported that the overall shell thickness of fresh and aged (stayed) eggs was 0.38 and 0.33 mm, respectively (Molla, 2010). This may be attributed that egg are laid at different time, may contribute for egg shell thickness difference.

According to Abera et al. (2012), egg shell thickness is a moderately heritable trait that is influenced by the genotype and calcium and phosphorous metabolism, which could vary across different ages of chickens and the nutrients (minerals) mentioned above.

Table 6: The shell thickness of egg in different regions (Ethiopia)

Chicken breed/ecotypes	Shell thickness (mm)	Place	Sources
Local chicken Hawassa	0.24	Ethiopia	Kejela *et al*. (2019)
Local chicken Yirgalem	0.19	Ethiopia	Kejela *et al*. (2019)
Sasso in Hawassa town	0.26	Ethiopia	Kejela *et al*. (2019)
Sasso in Yirgalem town	0.24	Ethiopia	Kejela *et al.* (2019)
Bovan browns in Hawassa town	0.24	Ethiopia	Kejela *et al.* (2019)
Bovan brown in Yirgalem town	0.32	Ethiopia	Kejela *et al*. (2019)
Local chicken in Jimma (fresh egg)	0.38	Ethiopia	Meseret (2010)
Local chicken in Jimma (aged egg)	0.33	Ethiopia	Meseret (2010)
Local chicken in Amhara region	0.31	Ethiopia	Abera *et al*. (2012)
Naked-neck chicken	0.37	Ethiopia	Melese *et al*. (2010)
Fulani ecotype	0.58	Nigeria	Fayye *et al*. (2015)

Chicken under Hawassa and Yirgalem was compared for Genotype by environment interaction.

Length of Egg:

The result showed that the egg length of chickens varied over two locations in southern Ethiopia (Kejela et al., 2019), showing an interaction effect of genotype by environment ($p<0.05$). A similar report was available showing the varied length of eggs across chicken genotypes, which is also influenced by non-genetic factors (Isidahomen et al., 2014). There have been different previous studies in different parts of Ethiopia. The egg length of the Sasso chicken breed in Hawassa and Yirgalem towns was reported at 55.77 and 55.63 mm, respectively (Kejela et al., 2019). According to the same authors, an average egg length of 55.79 mm and 55.39 mm was recorded for eggs collected from Bovans brown chickens kept in Hawassa and Yirgalem, respectively. On the other hand, a lower mean value was observed for Fayoumi crossed (50.0 mm) and Rhode Island Red crossed (51.4 mm) chickens kept under the Gurage Zone of Southern Ethiopia (Alewi et al., 2012). A similar result (51.3 mm) was reported based on research conducted in the Amhara region (Abera et al., 2012). A relatively higher average value (53.8 mm) of egg length was reported from research conducted in the western lowland area of the Tigray region (Markos et al., 2017). However, a lower mean value (48.3 mm) was reported for native chickens in Bangladesh (Islam and Dutta, 2010). Therefore, it is concluded that egg length is influenced by chicken genotype and environmental interaction.

Egg Width:

Markos et al. (2017) and Kejela et al. (2019) reported the presence of genotype-environmental interaction for differences among eggs from different chickens. According to Kejela et al. (2019), varied egg width was observed across genotype and location. The egg from local chicken was found to be narrower when compared with that from exotic chicken (Isidahomen et al., 2013). The findings of Abera et al. (2012) from the Amhara region and Markos et al. (2017) from the midland of the Tigray region were in agreement with the results of Isidahomen et al. (2013). The result of Kejela et al. (2019) showed a higher average egg width value for exotic chickens (Sasso and Bovan Brown), which also showed variation across the locations (Hawassa town and Yirgalem town). According to the results of Alewi et al. (2012) and Padhi et al. (2013), the width of the egg is associated with the stage of egg laying, in which the egg laid prior to mounting became larger than that laid at the start.

Genotype Environmental Interaction for Sheep Traits:

Productive Traits:

The growth traits of indigenous sheep reared in different parts of Ethiopia are presented in Table 7. According to the report by Taye et al. (2010), the productive performance of sheep is varied across different environmental conditions. The better birth weight performance was observed for Arsi-Bale indigenous sheep managed on farm than in station conditions (Legesse, 2008). However, sheep that were managed under on-station conditions showed a higher value (kg) for weaning weight as compared with those managed under farmer conditions, indicating a higher daily weight gain between the management conditions (Table 7).

Table 7: Birth and weaning weight (kg) of indigenous Ethiopia sheep under different management condition.

Indigenous sheep breed	Management Condition	Birth weight (Kg)	Weaning weight (Kg)	ADWG (gm/day)	Reference
Adal	On farm	2.5	13		
Adilo	On farm	2.29	11.18	98.77	Legesse, 2008
Arsi-bale	On farm	2.89	12.23	102.01	Legesse, 2008

Arsi-bale	On Station	2.8	13.5	Na	Brannang *et al.*, 1987
Bonga	On farm	2.86	11.6	Na	Belete, 2009
Horo	On Station	2.4	9.48	78	Tibbo, 2006
Menz	On farm	2.9	14.38	105	Hassen *et al.*, 2014
Menz	On station	2.06	8.64	72.6	Tibbo, 2006
Washara	On farm	2.7	11.9	59.1	Taye *et al.*, 2010

A similar condition was observed for the birth weight performance of indigenous Menz sheep between on-farm and on-station management conditions based on different time research works (Tibbo, 2006; Hassen et al., 2014). Observation based on these results showed improvement between 2006 and 2014 in terms of both birth weight (2.06 vs. 2.9) and weaning weight (8.64 vs. 14.38), for which the main reason could be a difference in time and management conditions**.**

Reproductive Traits of Sheep:
A comparative study of Begait sheep in government ranches, private ranches, and private farms was conducted in the northern western part of Ethiopia (Ashebir et al., 2016). The author reported a relatively higher twining (13.4%) rate in government ranches and the lowest in private farms (6.52%). The mean value for age at first service, service period, age at first lambing, and lambing interval was reported at 579.61±0.6, 206.25±0.2, 731.67±0.3, and 256.60±60 days, respectively (Ahebir et al., 2016). The authors further reported that service period and age at first service showed significant differences among different locations. However, lambing interval and age at first lambing were not affected by location at $P<0.05$.

Table 8: The Reproductive performance (Mean±SE) of Begait sheep kept under three locations studied

Location	N	AFS (days)	SP (days)	AFL (days)	LI (days)
Gov. Ranch	50	576±1.1^{a}	206.48±0.4^{b}	733±0.5^{b}	254.32±0.5^{a}
Private Ranch	50	582±0.9^{b}	207.10±0.3^{b}	730±0.2^{a}	259.80±0.6^{a}
Private Ranch	50	580±0.8^{b}	205.16±0.3^{a}	732±0.3$_{b}$	257.82±0.6^{a}
Mean	50	579.61±0.6	206.25±0.2	731.67±0.3	256.60±0.3

AFS – Age at first service, SP – Service period, AFL – Age at first lambing and LI – Lambing interval

Previous studies confirmed that age at first lambing showed variation among breeds and production systems. Study by Legesse (2008) and Girma (2008) showed a big variation in age at first lambing among production systems and breeds.

SUMMARY AND RECOMMENDATION

The review was undertaken with the general aim of assessing the effects of genotype-environment interaction on the productivity and performance of livestock in Ethiopia and tropical countries. Genotype-environment interaction is defined as a change in the relative performance of two or more genotypes measured in two or more environments. The issues of GEI arise when the performance of the different genotypes is not equally influenced by the different environments. Genetic correlation and estimates of heritability between traits were commonly used to assess the effect of GEI influence on the phenotypic performance of animals. Exiting evidence indicated that a genetic correlation lower than 0.8 between traits requires consideration of GEI influence when planning for animal genetic evaluation and sire selection. This review observed different milk production-related traits such as lactation milk yield, initial milk yield, and average milk yield of cattle, as indicated by the genetic correction of these traits across locations.

Significant GEI influence was also observed for the growth traits of cattle in Ethiopia and other tropical countries. Similarly, the effect of GEI prevailed for chicken egg parameters such as egg width, shell thickness, length of egg, and width of egg among chicken breeds investigated in different environments. Sheep growth traits (birth and weaning) and productive traits (age at first services, age at first lambing, and service periods) were significantly influenced by the effects of GEI. General genetic correlation and heritability estimates in the tropics and Ethiopia showed significant GEI for the productive and reproductive performance of animals, and hence the genetic evaluation and selection of animals require information from intervention locations to accurately select the most appropriate animals for each location. Further in-depth research and continued evaluation of this interaction are essential for the development of targeted breeding programs and improved livestock management practices across various agro-ecological zones in the tropics.

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