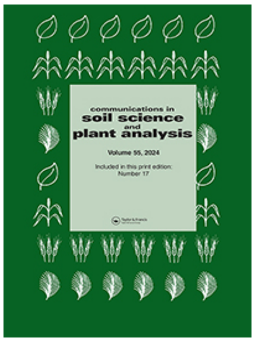

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ABSTRACT
This study aims to develop an Artificial Neural Network (ANN) modeling to be trained to forecast the effects of different irrigation water levels and fertilizer doses on the hay yield and some quality traits of herbal parts of Sorghum × Sudan grass hybrid (*Sorghum sudanense vs. Sorghum bicolor*). The ANN model was developed on the limited field experiments implemented in Bilecik, Turkey, for 2 years in 2021 and 2022. Experiments were conducted in split-plot design with three replications. In the study, three irrigation levels (I100, I60, and I30) were placed in the main parcels, and four fertilizer levels (N0, N50, N100 and N150 kg ha^{-1}) were placed in the sub-parcels. Irrigations were made in three critical periods according to the amount of cumulative evaporation occurring in the Class A Pan. The results showed that irrigation and fertilization are important in terms of yield and quality characteristics. The yield increased depending on the irrigation and fertilization dose, and the highest value was obtained from the I100 × N150 interaction (28.10 t ha^{-1}). The highest protein yield was determined from the I60 × N150 (2.37 t ha^{-1}) interaction, and the Relative Feed Value (RFV) value was determined from the I30 × N150 (92.17) interaction. Irrigation Water Use Efficiency (IWUE) and Water Use Efficiency (WUE) values increased with decreasing irrigation amount, and the highest IWUE was determined from I30 and the highest WUE was determined from I60 irrigation subjects. According to the field experiments and ANN model, the I80 irrigation with 100 kg ha^{-1} nitrogen doses would suit the feed yield and quality of Sorghum × Sudan grass hybrid.

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Artificial neural network; deficit irrigation; fertilization; hay yield; protein quality; roughage

Introduction

Due to the increasing world population and climate change, our agricultural areas and natural resources are decreasing day by day. In particular, the pressure on water resources has been felt more in recent years. When we look at the sectoral utilization of the existing water assets in the world, the agricultural sector is the largest user of water, with approximately 70%. Therefore, it has become a global necessity to use resources efficiently in the agricultural sector. For this reason, in recent years, serious measures have been taken to ensure effective water use and water conservation in the agriculture sector. Deficit irrigation is one method that reduces the amount of water given to plants and saves water compared to full irrigation.

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Deficit irrigation is an essential and sustainable production strategy applied in regions with limited water resources (Geerts and Raes 2009). The aim is to increase plant water use efficiency by reducing the amount of irrigation water or the number of irrigations. The plant to be irrigated with limited irrigation is exposed to water stress at specific rates during any period of the development period or throughout the season, and it is expected to save irrigation water without causing a significant decrease in yield (Kırda 2002).

Fertilization, along with irrigation, is one of the most critical inputs to increase productivity in plant production. While the use of an appropriate amount of fertilizer increases the yield, when it is used excessively, some of the fertilizers are washed from the soil or become unfixable in the soil, thus reducing the effectiveness of the fertilizer. Therefore, a planning should be made before applying fertilizer to the soil. There are 16 elements that are essential in plant nutrition. To effectively use these 16 important components in plant nutrition, the soil must be given the exact dosage that each of these elements needs to grow. Because the use of too much fertilizer will not increase the yield and may also cause soil pollution. That is why it is so important to avoid over-fertilizing the soil and instead provide the plant with the proper amount of fertilizer.

Sorghum-sudangrass (*SS*) hybrids are a cross between *Sorghum bicolor* (L.) Moench and *Sorghum Sudanese* (Piper) Stapf and have wide adaptability. It is a plant with a sugar-rich stem and a high biomass yield. Due to its lower water and fertilizer needs, it is very suitable for cultivation in marginal areas. SS hybrids have shown a great increase in animal nutrition, especially in recent years, due to their features such as ease of cultivation, rapid settlement, growth and rich nutrient content.

For an agricultural activity's field experiments to produce findings that are acceptable, additional time, work, land, and money are required. An Artificial Neural Network (ANN) model sensitively measures the degree of influence since it can successfully yield agreeable predictions with high scores (Arslan 2011, 2014). The ANN is a useful tool for the limited data set, since it is a modeling method to forecast the values that the network has never met before. This modeling with limited data is one of the novel sides of this study since the data achievement is so hard due to the large required study area, long experimental period, and changeable environmental conditions. In this study, ANN modeling was first developed and used to forecast the effects of different irrigation water levels and fertilizer doses on the hay yield and some quality traits of the herbal parts of the SS hybrid remaining after seed harvesting. Thus, more precise results can be obtained with fewer field experiments. Twelve parametric data sets were obtained through the 36 measured annual values from field research for use in the ANN structure.

Material and methods

Research site

Field experiments were implemented in the Application and Research Station (40° 6` N, 30°.0` E) at the University of Bilecik Seyh Edebali, in Bilecik, Turkey. The studies were carried out in the 2021 and 2022 growing seasons. Based on long-year meteorological data, the average temperature in Bilecik is 12.5°C, and the annual average rainfall is 459.3 mm. For the 2021 and Farhadi et al. (2022) tomato growing seasons, when the study was conducted, the total rainfall was 94.7 mm and 116.3 mm, respectively. Soil analysis was done before the study started, and some physical and chemical soil properties were determined. According to the results, the land will have a loamy soil structure, and other soil properties are given in Table 1.

Experimental design and treatments

In the study, "Aneto" sorghum × sudangrass hybrid (SS) was used as crop material. The Aneto variety is drought resistant, rapid growing and of high silage quality. The experiments were carried out using a split-plot design three replication. The plot measures 6 × 2.8 m (16.8 m^2), with a plant

Table 1. Some properties of the experiment area soil.

Depth (cm)	Texture	Field capacity PW (%)	Volume weight (g cm^{-3})	PH	Organic matter	Phosphorus P_2O_5 (kg da^{-1})	Potassium K_2O (kg da^{-1})
0–30	CL	27.87	1.26	7.77	1.18	26.74	116.28
30–60	L	24.57	1.21	7.81	1.24	27.45	91.59
60–90	L	26.67	1.27	7.71	2.07	21.02	96.42

spacing of 5 cm on each row and a row spacing of 70 cm overall. There are four rows each parcel. The study was designed with three irrigation subjects (100% (I100), 60% (I60), and 30% (I30) of the evaporation measured in the Class A Pan) for the main plots and four nitrogen doses (0 kg ha^{-1}(N0), 50 kg ha^{-1}(N50), 100 kg ha^{-1} (N100), 150 kg ha^{-1}(N150)) for the subplots (Table 2). All plots applied 80 kg of P_2O_5 of DAP base fertilizer per hectare during planting. Considering the nitrogen we gave with the base fertilizer while fertilizing applications, the missing amounts were completed to 50, 100, and 150 kg per ha and given to other parcels. Irrigation was done in the form of supplementary irrigation during the three critical periods determined for the plant. The first irrigation was done when the plants reached 30–35 cm in height, the second at the beginning of flowering, and the third when the panicle emerged.

Irrigation is calculated as in equation 1 according to the amount of cumulative evaporation occurring in the class A pan during the specified critical periods (Kanber 1984):

$$I = A \times kcp \times Ep \times P \tag{1}$$

where I is the irrigation amount (mm), A is the parcel area (m^2), kcp plant-pan coefficient (0, 0.30, 0.60, 1.00) E_p is the cumulative evaporation amount from class A-pan (mm), and P is the percentage of vegetation.

The soil water content was measured gravimetrically at 0.3 m depth to 1.2 m throughout the growing season. Crop evapotranspiration is calculated using a water balance equation (Shen et al. 2019):

$$ETa = I + P + W \pm \Delta S - D - R \tag{2}$$

where I is the irrigation amount (mm), P is the seasonal amount of precipitation (mm), W is the groundwater flow into the root zone (mm), ΔS is the change in soil moisture content (mm), D is the deep drainage losses (mm) and R is the surface runoff. In the equation, the *P*-value is taken from the Bilecik State Meteorology Station. W was ignored as the groundwater level was 15 m below the ground surface, which was not deep enough to affect the growth of Sorghum Sudan grass. In the drip irrigation method, capillary rise (R) is considered zero since there is no surface flow or groundwater in the area. Since no irrigation is subject to exceeding the field capacity, the deep infiltration (D) value was also taken as zero (Hanks 1974).

Table 2. Irrigation water level and nitrogen-dose subjects that constitute the up the main parcels and sub-parcels.

Main plots treatments		Sub plots treatments	
I30	The subject to which 30% of the cumulative evaporation occurring in the class A pan is applied	N0	The subject where no fertilizer is applied
I60	The subject to which 60% of the cumulative evaporation occurring in the class A pan is applied	N5	Subject to which 5 kg nitrogen is applied per decare
I100	The subject to which 100% of the cumulative evaporation occurring in the class A pan is applied	N10	Subject to which 10 kg nitrogen is applied per decare
		N15	Subject to which 15 kg nitrogen is applied per decare

Water productivity

Water use efficiency and irrigation water use efficiency values are the most important variables to consider when analyzing correlations between plant-water yields. The yield values acquired per unit of water applied to the plant are shown by irrigation water use efficiency, and the yield values obtained versus seasonal plant water consumption are shown by water use efficiency. These values are calculated from the equations determined by Howell et al. (1990):

$$IWUE : \frac{Y}{I} \tag{3}$$

$$WUE : \frac{Y}{ETa} \tag{4}$$

where IWUE is the irrigation water use efficiency (kg m^{-3}), Y is the yield (kg da^{-1}), I is the volume of seasonal irrigation water applied (m^3 da^{-1}), WUE is the water use efficiency (kg m^{-3}), and ETa is the actual seasonal evapotranspiration (m^3 da^{-1}).

Hay yield and quality analysis

The plants were harvested at the seed maturation stage, the seeds were separated, and the remaining plant parts were used in the measurements and analyses. The hay yield was determined after drying the samples at 65°C until constant weight. Crude protein ratio, acid detergent fiber (ADF) and neutral detergent fiber (NDF) were determined by using Near Reflectance Spectroscopy. Relative feed value (RFV) is estimated according to the following equations adapted from Rohweder, Barnes, and Jorgensen (1978):

$$DDM = 88.9 - (0.779 \cdot ADF) \tag{5}$$

$$DMI = \frac{120}{NDF} \tag{6}$$

$$TDN = 96.35 - ADF \cdot 1.15 \tag{7}$$

$$RFV = \frac{DDM \cdot DMI}{1.29} \tag{8}$$

where DDM is the digestibility of dry matter (%), DMI is the dry matter intake (%), TDN is the total digestible nutrient (%), and RFV is the relative feed value (%).

Statistical analysis of the field experiments

Yield and other determined quality parameters were subjected to analysis of variance (ANOVA) using Minitab 19 software. The significance of irrigation and nitrogen doses was determined using the F test. When the F test was significant, the Tukey test ($p < .05$) was used to compare the group means of irrigation and nitrogen-dose treatments and their interactions.

ANN modelling

In the study, the feed-forward back-propagation learning algorithm, which is most widely used, was handled in the multi-layer neural network (MLNN) architecture, as well as the Levenberg-Marquardt (LM) algorithm, which was selected as the training algorithm since it has successful scores (Tugcu and Arslan 2017). All the training and testing values were normalized in the range of 0.3 and 0.7 to scale all parameters to the equivalent degree for faster and more sensitive results (Arslan et al., 2024; Boukelia et al., 2016). The non-linear transfer function, namely the logarithmic sigmoid (logsig), was used to forecast the complex relations for the related activity (Arat and Arslan 2017). The logsig function for the inputs is given as:

$$f(\mathrm{n}) = \frac{1}{1 + e^{-\mathrm{n}}} \tag{9}$$

where n is the weighted sum given by:

$$\mathrm{n_j} = \sum\nolimits_{\mathrm{i}=1}^{\mathrm{k}} \mathrm{w_{i,j} y_i} + \mathrm{b_j} \tag{10}$$

Here, w is the weight, y is the output value, and b is the bias. Seventy-five percent of the experiments were randomly selected for the training of the ANN model; the remaining part was used in the testing stage. The accuracy of the network was separately measured for the training and testing stages by the coefficient of multiple determinations (R^2), mean percentage error (*MPE*), Root Mean Square Error (*RMSE*), and co-variation (*CoV*). In terms of the ANN output (y_{ANN}), experimental data (y_{actual}) and the mean experimental data ($\bar{y}_{actual}$), R^2, *MPE* and *CoV* for a number of *k* data are, respectively, given by:

$$R^2 = 1 - \frac{\sum\nolimits_{\mathrm{i}=1}^{\mathrm{k}} \left(y_{ANN} - y_{actual}\right)^2}{\sum\nolimits_{\mathrm{i}=1}^{\mathrm{k}} \left(y_{actual} - \bar{y}_{actual}\right)^2} \tag{11}$$

$$MPE = \frac{\left(\frac{\sum\nolimits_{\mathrm{i}=1}^{\mathrm{k}} y_{ANN} - y_{actual}}{\left|Max\left(y_{actual}\right) - Min\left(y_{actual}\right)\right|}\right)}{k} \times 100 \tag{12}$$

$$RMSE = \sqrt{\frac{\sum\nolimits_{\mathrm{i}=1}^{\mathrm{k}} \left|y_{actual} - y_{ANN}\right|^2}{k}} \tag{13}$$

$$CoV = \frac{\sum\nolimits_{\mathrm{i}=1}^{\mathrm{k}} \left(y_{ANN} - \bar{y}_{ANN}\right)\left(y_{actual} - \bar{y}_{actual}\right)}{k} \times 100 \tag{14}$$

The ANN topology comprised three layers: input, hidden and output. In the training stage, different numbers of neurons were run to obtain the best structure. According to this, the best structure was obtained as the topology with five neurons. The ANN structure is given in Figure 1.

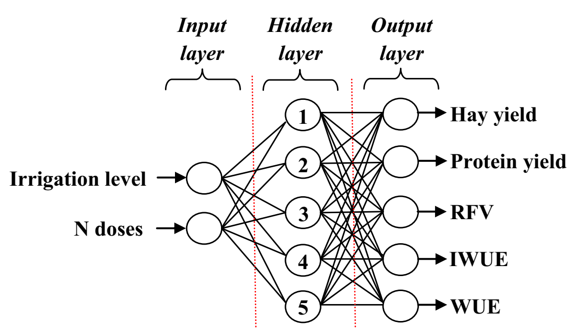


Figure 1. The structure of the used ANN topology.

With the increase in the neuron number, it was determined that the forecasting sensitivity decreased, although the learning sensitivity increased. The main reason for this event is memorizing the results by the network. The comparison of ANN results and experimental data is given in Figure 2. The results of the statistical evaluation are given in Table 3.

According to statistical evaluation, R^2 values were obtained as 0.995, 0.943, 0.903, 0.982, and 0.992 for the training stages of hay yield, protein yield, RFV, IWUE, and WUE, respectively. These values were recorded as 0.969, 0.910, 0.840, 0.919, and 0.9154 for the testing stages of hay yield, protein yield, RFV, IWUE, and WUE, respectively. *MPE* values were obtained as 1.981%, 6.455%, 7.854%, 3.440%, and 2.585% for the training stages of hay yield, protein yield, RFV, IWUE, and WUE, respectively. These values were recorded as 6.756%, 16.164%, 14.467%, 12.805%, and 8.716% for the testing stages of hay yield, protein yield, RFV, IWUE, and WUE, respectively. *RMSE* values were obtained as 38.112, 11.917, 0.894, 0.116, and 0.045 for the training stages of hay yield, protein yield, RFV, IWUE, and WUE, respectively. These values were recorded as 86.726, 16.864, 2.320, 0.476, and 0.153 for the testing stages of hay yield, protein yield, RFV, IWUE, and WUE, respectively. *CoV* values were obtained as 2.093, 7.055, 1.133, 2.701 and 1.544 for the training stages of hay yield, protein yield, RFV, IWUE, and WUE, respectively. These values were recorded as 5.183, 9.118, 2.707, 9.203, and 4.693 for the testing stages of hay yield, protein yield, RFV, IWUE, and WUE, respectively. The results show that the developed ANN model is acceptable for forecasting agricultural activities.

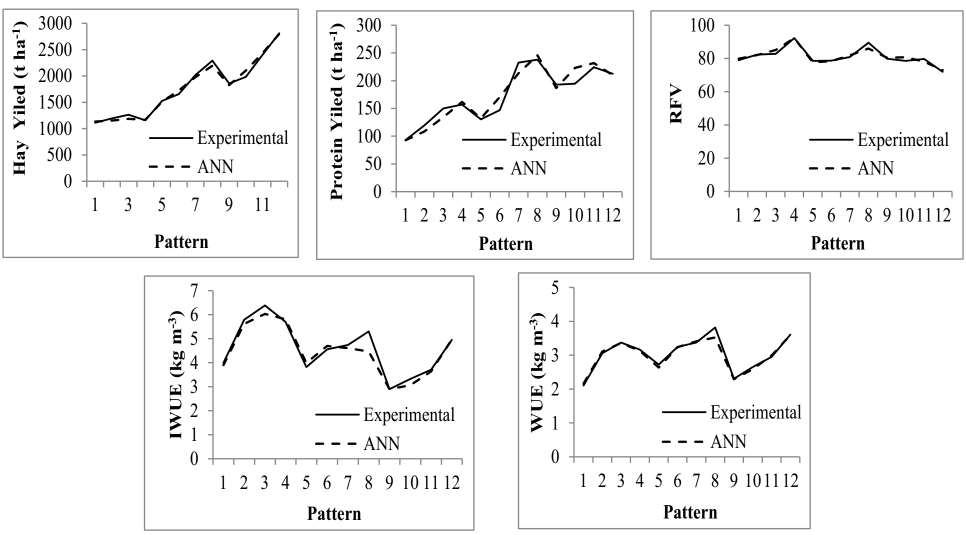


Figure 2. The comparison of experimental and ANN results.

Table 3. Validation of the ANN results.

	Hay yield	Protein yield	RFV	IWUE	WUE
Training					
R^2	0.995	0.943	0.903	0.982	0.992
MPE	1.981	6.455	7.854	3.440	2.583
RMSE	38.112	11.917	0.894	0.116	0.045
CoV	2.093	7.055	1.133	2.701	1.544
Testing					
R^2	0.969	0.910	0.840	0.919	0.945
MPE	6.756	16.164	14.467	12.805	8.716
RMSE	86.726	16.864	2.320	0.476	0.153
CoV	5.183	9.118	2.707	9.203	4.693

Result and discussion

The effects of irrigation level, fertilizer doses and their interactions with each other on hay yield and protein yield were found to be statistically significant (Table 4). According to the interactions, the highest hay yield was obtained from $I_{100} \times N_{100}$ (28.20 t ha^{-1}), while the lowest was obtained from $I_{30} \times N_0$ (11.09 t ha^{-1}) and $I_{30} \times N_{50}$ (11.92 t ha^{-1}) treatment. When we look at the applications separately, the highest hay yield was obtained from I_{100} irrigation and the N_{150} fertilizer dose. Protein yield ranged between 0.93 and 2.37 t ha^{-1} (Table 3). The highest protein yield was obtained from the $I_{60} \times N_{150}$ interaction, and the lowest protein yield was obtained from the $I_{30} \times N_0$ interaction. The most significant values were found from the I_{100} irrigation subject and N_{100} and N_{150} fertilizer doses when we examined the effects of the applications on the protein yield separately. Mineral fertilizers and irrigation play a vital role in increasing crop yield. The results of the study showed us that with the increase in both irrigation level and fertilizer dose, weed yield and protein yield increased. The present findings on protein yields were similar to those of Coban and Acar (2018) and Gonulal (2020).

Previous studies indicated a linear relationship between the amount of fertilizer and irrigation and yield (Hussein and Alva 2014; Hussein and Sabbour 2014; Khalaf et al. 2019). Hussein and Sabbour (2014) reported that the hay yield of sorghum at different irrigation and fertilization levels varied between 10.3 and 16.8 t ha^{-1}. The variation in results for the same trait between studies can be attributed to differences in growing conditions, cultivars, cultural treatments, and ecology.

A linear relationship was determined between the applied nitrogen dose ($y = 2.062X+12.57$ ($R^2 = 0.976$)), irrigation level ($y = 5.41X+6.89$ ($R^2 = 0.975$)), and hay yield. Therefore, hay yield increased with the increase in nitrogen dose and irrigation level (Figure 3).

The separate treatments and interactions had a significant effect on RFV (Table 5). According to the interactions, the highest RFV was determined at 92.17 ($I_{30} \times N_{150}$) and 89.39 ($I_{60} \times N_{150}$), while the lowest was 71.95 ($I_{100} \times N_{15}$). RFV is calculated with ADF and NDF and reveals the digestibility of the plant. Therefore, it is desirable to have a high RFV. In the study, the SS plant reached the highest RFV values at N_{100} and N_{150} fertilizer doses and I_{30} and I_{60} irrigation levels. Kaplan et al. (2014) indicated that increasing water levels also increases stem ratios, thus affecting ADF and NDF contents. Accordingly, I_{100} had the lowest RFV value in this study. If the RFV exceeds 151, it is the beginning quality standard. If RFV is between 151 and 125, it is the first quality standard. If RFV is between 124 and 103, it is the second quality standard. If RFV is between 102 and 87, it is the third quality standard. If RFV is between 86 and 75, it is the fourth quality standard. If RFV is lower than 75 IF, it is the fifth quality standard in terms of forage quality (Rohweder, Barnes, and Jorgensen 1978). The RFV values determined in the study showed that the examined SS hybrid samples were between the fourth and third quality classes (Table 5).

Irrigation water use efficiency (IWUE) and water use efficiency (WUE) are the most important parameters for evaluating irrigation practices. Water use efficiency (WUE) refers to hay yield per unit

Table 4. Irrigation × nitrogen dose interaction affects forage yields of *SS* hybrid.

IL	N0	N50	N100	N150	Avarage**
Hay yield (t ha^{-1})**					
I30	11.09^{h}	11.92^{h}	12.65^{gh}	11.56^{h}	***11.80^{c}***
I60	15.23^{fg}	16.53^{ef}	20.20^{cd}	22.90^{bc}	***18.71^{b}***
I100	18.59^{de}	19.81^{d}	24.00^{b}	28.10^{a}	***22.62^{a}***
Avarage**	***14.97^{c}***	***16.09^{c}***	***18.95^{b}***	***20.89^{a}***	
Protein yield (t ha^{-1})**					
I30	0.93^{f}	1.19^{ef}	1.50^{de}	1.57^{cde}	***1.30^{c}***
I60	1.30^{ef}	147.06^{e}	2.32^{ab}	2.37^{a}	***187^{b}***
I100	1.92^{bcd}	1.94^{abc}	2.24^{ab}	2.12^{ab}	***2.06^{a}***
Avarage**	***1.38^{b}***	***1.53^{b}***	***2.02^{a}***	***2.02^{a}***	

**: p < .01. Year: **; Irrigation level (IL): **; Fertilization doses (FD); ILXDS: **; SS: Sorghum x sudangrass.
The different superscript letters in the table indicate the order of statistical significance, with "a" being the highest and "h" the lowest.

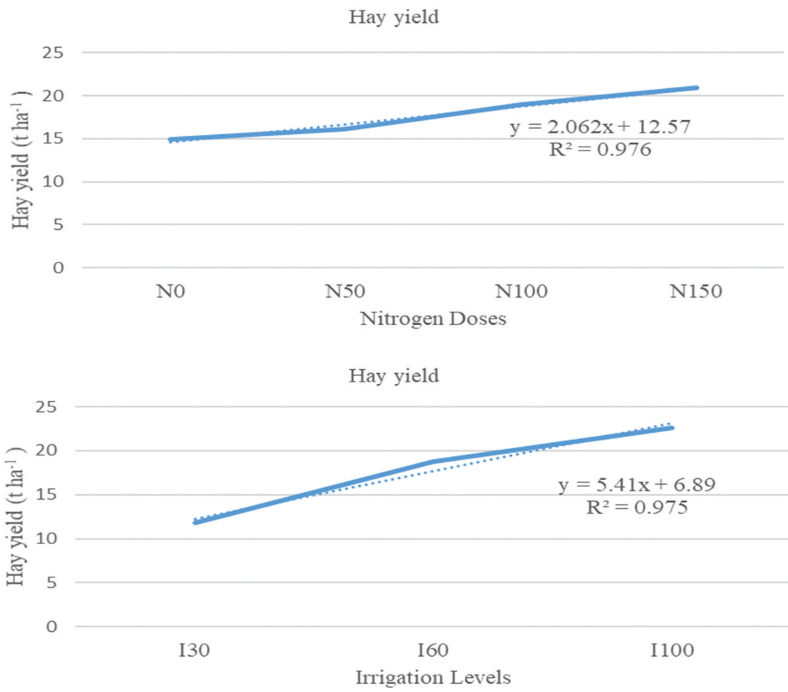


Figure 3. The relationship between nitrogen doses and irrigation level with hay yield.

Table 5. Irrigation and nitrogen-dose interaction effects on RFV of *SS* hybrid.

	Relative feed value (RFV)**				
IL	N0	N50	N100	N150	Avarage**
I30	79.00[cd]	82.30[bc]	82.75[bc]	92.17[a]	***84.06[a]***
I60	78.45[cd]	78.67[cd]	80.88[c]	89.39[ab]	***81.85[a]***
I100	79.77[c]	78.54[cd]	79.69[cd]	71.95[d]	***77.49[b]***
Avarage**	***79.07[b]***	***79.84[b]***	***81.11[ab]***	***84.50[a]***	

**: p < .01. Year: **; Irrigation level (IL): **; Fertilization doses (FD); ILXDS: **; SS: Sorghum x sudangrass.
The different superscript letters in the table indicate the order of statistical significance, with "a" being the highest and "d" the lowest.

Table 6. Irrigation water use and water use efficiency values of *SS* hybrid.

Irrigation levels	N doses	IWUE **(kg m^{-3})	WUE **(kg m^{-3})
I30	N0	5.57 [ab]	2.95 [cde]
	N5	5.98 [ab]	3.17 [bcd]
	N10	6.35 [a]	3.36 [bc]
	N15	5.8 [ab]	3.07 [bcd]
I60	N0	3.82 [de]	2.73 [def]
	N5	4.15 [cd]	2.96 [cde]
	N10	5.07 [bc]	3.62 [ab]
	N15	5.73 [ab]	4.10 [a]
I100	N0	2.88 [f]	2.30 [f]
	N5	3.07 [ef]	2.45 [ef]
	N10	3.72 [def]	2.97 [cde]
	N15	4.36 [cd]	3.48 [bc]

: p < .01. Year:; Irrigation level (IL): **; Fertilization doses (FD); ILXDS: **; SS: Sorghum x sudangrass.
The different superscript letters in the table indicate the order of statistical significance, with "a" being the highest and "f" the lowest.

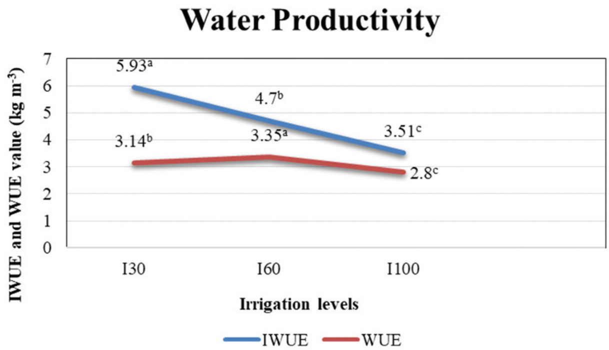
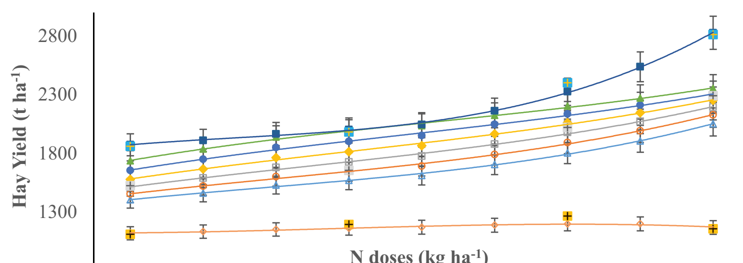


Figure 4. According to the average irrigation water levels, Irrigation water use and water use efficiency values of SS hybrid.

of water used by the plant, and irrigation water use efficiency (IWUE) refers to hay yield per unit of water applied to the plant (Table 6 and Figure 4). The table shows that the IWUE value increased as irrigation water decreased. The highest IWUE value of 6.35 kg m^{-3} was obtained from $I_{30} \times N_{100}$, and the lowest IWUE value of 2.88 kg m^{-3} was obtained from $I_{100} \times N_0$. When we look at the WUE values, the highest value was obtained from $I_{60} \times N_{150}$ as 4.10 kg m^{-3}, and the lowest was obtained from I_{100} N_0 as 2.30 kg m^{-3}. When we look at the averages of irrigation subjects, the highest IWUE value was obtained for I_{30}, and WUE value was obtained for I_{60} irrigation subjects. As the amount of irrigation water decreases, the increase in water productivity is an essential parameter for effective water use. When we compare irrigation issues, the issue of I_{60} comes to the fore. In studies on this subject, researchers have reached similar results and reported that water productivity increases as the amount of irrigation water decreases (Aydinsakir and Erdurmus 2021; Farhadi et al. 2022; Khalaf et al. 2019).

Figure 5 shows the ANN results for hay yield. The ANN results show that the deviation from experimental (Exp.) results is in the 5%. The ANN outputs show that hay yield increases with the increase in irrigation and fertilizer, as expected.



Irrigation	0	20	40	50	60	80	100	120	150
I30	1119.18	1133.35	1151.14	1160.73	1170.29	1187.52	1198.63	1198.8	1167.65
I40	1403.29	1459.81	1529.13	1568.55	1610.94	1703.38	1802.94	1904.82	2050.70
I50	1452.57	1519.92	1599.91	1644.21	1690.94	1789.74	1891.65	1991.45	2127.12
I60	1510.60	1588.65	1678.09	1726.20	1775.89	1877.58	1977.94	2072.08	2194.00
I70	1577.73	1665.50	1762.21	1812.61	1863.54	1964.35	2059.61	2145.42	2251.83
I80	1653.21	1748.71	1849.57	1900.43	1950.69	2046.99	2134.34	2210.18	2300.76
I90	1735.44	1835.73	1937.14	1986.64	2034.55	2123.75	2202.20	2269.33	2352.58
I100	1872.64	1909.44	1964.35	2000.87	2044.96	2161.39	2324.65	2537.47	2826.79
I30 (Exp.)	1109.29			1192.14			1265.00		1156.43
I60 (Exp.)	1523.57			1653.57			2020.00		2290.71
I100 (Exp.)	1859.29			1981.43			2400.36		2810.71

Figure 5. ANN results for hay yield.

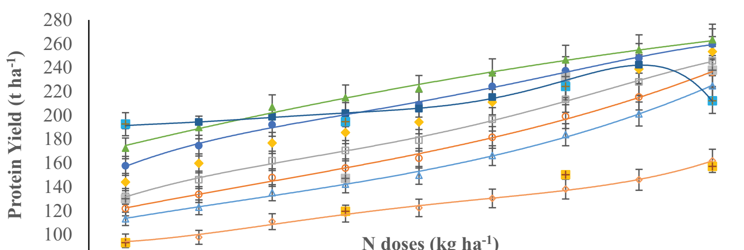
However, the hay yield decreases after $N = 120$ kg ha^{-1} for I_{30}. This means that the N cannot disperse sufficiently on the land. After I_{40}, the irrigation effect on the hay yield shows a linear increase with the N dose. For I_{100}, the hay yield has a sudden increasing tendency with the N dose after $N = 80$ kg ha^{-1}. This means that the N has an effective dispersion for the higher irrigation rates. Indeed, irrigation and fertilization show a positive correlation regarding plant growth. The minimum variation per N dose is 0.04% (for I_{40}), whereas the maximum is 0.57% (for I_{100}). According to irrigation level, the minimum variation per irrigation level is 0.02% (for $N = 150$ kg ha^{-1}), whereas the maximum is 7.56% (for $N = 150$ kg ha^{-1}).

Figure 6 shows the ANN results for protein yield. The ANN results show that the deviation from experimental (Exp.) results is in the 6%. Protein yield variation tends to increase with the increase of N doses. However, protein yield starts to decrease after $N = 120$ kg ha^{-1} for the highest irrigation level (I_{100}). This can be explained by the higher irrigation preventing the efficient use of N since it is not sufficiently mixed with the land. So, the irrigation level after I_{90} is not suitable for production with higher protein content. The minimum variation per N dose is 0.05% (for I_{100}), whereas the maximum is 0.58% (for I_{40}). According to irrigation level, the minimum variation per irrigation level is 0.10% (for $N = 20$ kg ha^{-1}), whereas the maximum is 3.88%(for $N = 150$ kg ha^{-1}).

The ANN results for RFV are given in Figure 7. The RFV for I_{40} decreases till $N = 80$ kg ha^{-1}, then increases with the increase of the N doses. The RFV for I_{50} decreases till $N = 40$ kg ha^{-1}, then increases with the increase of the N dose. I_{90} is the best practice for RFV. However, the lower irrigation level (I_{30}) is the best for the higher N doses ($N > 150$ kg ha^{-1}). From the RFV point of view, I_{100} is not a suitable practice after $N = 20$ kg ha^{-1}.

As seen in Figure 8, high N doses for the IWUE value are suitable for low irrigation levels. I30 is the best practice for IWUE, although IWUE has a decreasing tendency after $N = 100$ kg ha^{-1}. I100 would be the best practice for the higher N dose since it has a more prominent increasing tendency after $N = 60$ kg ha^{-1}.

According to Figure 9, I40 is the best practice, although WUE has a decreasing tendency after $N =$ 120 kg ha-1. I50 would be the best practice until $N = 60$ kg ha^{-1}. I100 would be the best practice for the higher N doses since it has a more prominent increasing tendency.



Irrigation	0	20	40	50	60	80	100	120	150
I30	94.83	97.69	110.92	117.61	122.43	130.41	138.14	146.03	161.85
I40	113.23	122.95	135.14	142.16	149.73	166.24	183.79	201.21	224.69
I50	121.77	133.57	147.80	155.71	164.05	181.49	198.98	215.36	236.08
I60	132.05	145.90	161.87	170.41	179.17	196.69	213.27	227.97	245.59
I70	144.07	159.73	176.87	185.66	194.40	211.15	226.15	238.84	253.38
I80	157.65	174.60	192.11	200.71	209.02	224.29	237.31	247.90	259.63
I90	172.36	189.82	206.84	214.84	222.35	235.65	246.47	254.87	263.33
I100	191.46	194.29	198.75	201.79	205.50	215.31	228.54	242.49	211.62
I30 (Exp.)	93.19			119.50			150.13		157.14
I60 (Exp.)	130.09			147.06			232.45		237.83
I100 (Exp.)	192.67			194.70			224.18		212.29

Figure 6. ANN results for protein yield.

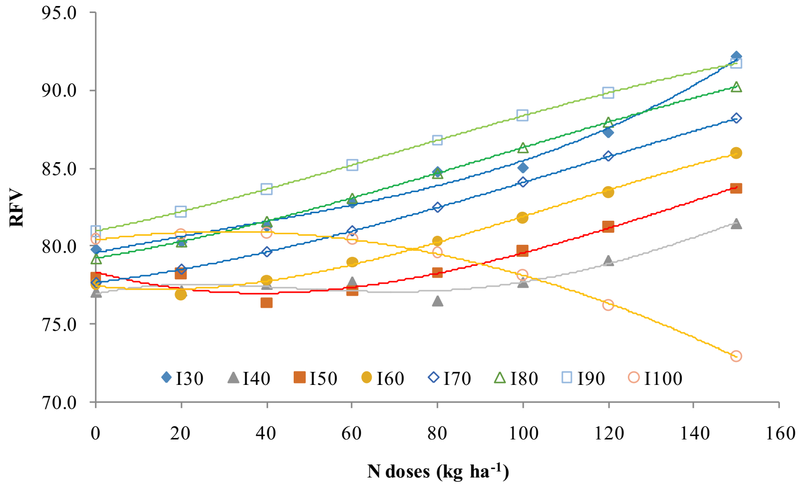


Figure 7. ANN results for RFV.

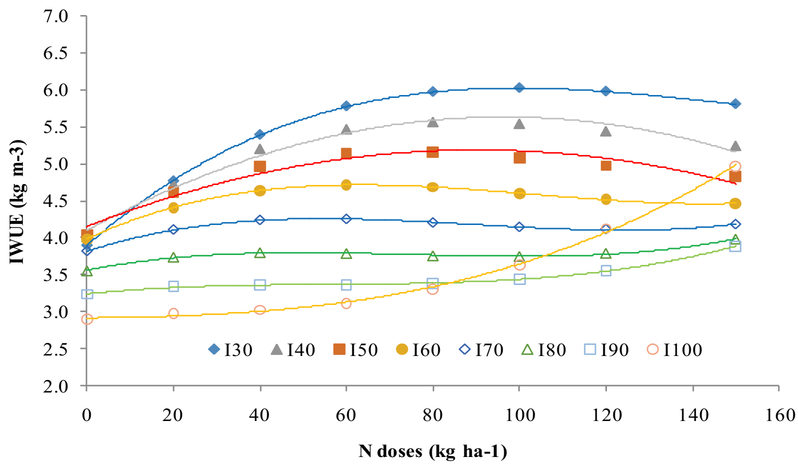


Figure 8. ANN results for IWUE.

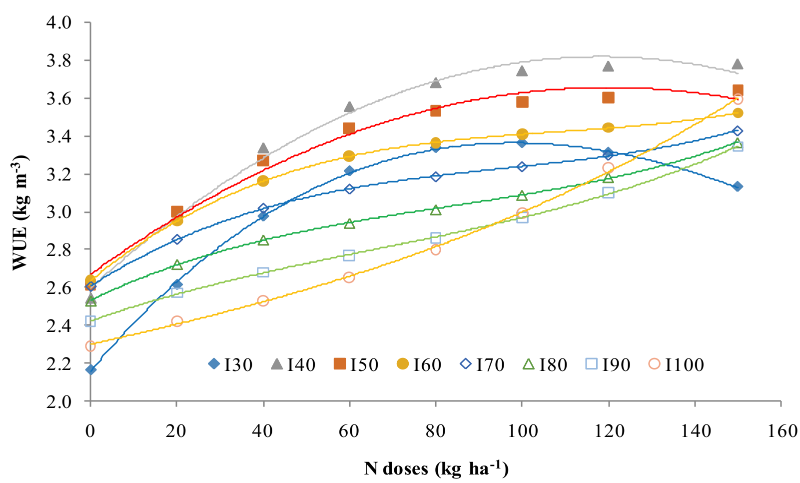


Figure 9. ANN results for WUE.

Conclusion

In this study, an ANN model was developed to determine the forage yield and quality of SS hybrid plant parts that remained after seed harvesting. The developed ANN model investigated the effect of fertilizer and irrigation on the hay yield, protein yield, RVF, IWUE, and WUE. It was determined that the structured ANN model could successfully observe these effects with limited land experiments. The best ANN model was obtained for the structure with one hidden layer, including five neurons. On the other hand, increasing hay yield, protein yield, and decreasing RFV with increasing irrigation levels. Accordingly, when yield, RFV, and water use efficiency are evaluated together, it is concluded that N_{10} and I_{100} levels would be suitable for the plant. However, when the field studies and the ANN model were assessed together, it was determined that the I_{80} irrigation water with 100 kg t ha^{-1} nitrogen doses would be suitable for the feed yield and quality of the Sorghum × Sudan grass hybrid. This means that the exact yield and quality can be obtained with 20% less irrigation given to the plants. In conclusion, the data obtained are of great importance in terms of the effective use of water resources that have decreased in recent years and contributing to the farmer's economy.

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