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# DETERMINATION OF THE FORAGE YIELD AND GROWTH PARAMETERS OF MAIZE (*Zea mays* L.) WITH QUINOA (*Chenopodium quinoa*) INTERCROPPING AT DIFFERENT PLANT MIXTURES

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**ABSTRACT**

**The aim of this study was to grow maize with quinoa plants as an alternative in an intercropping system and to determine the effects of different plant mixtures on production. For this purpose, a trial was carried out in the coastal Aegean region (Aydın Province) of Turkey under Mediterranean climate conditions. In addition to 100% maize and 100% quinoa (monocultures), 3 different mixtures (75% maize-25% quinoa, 50% maize-50% quinoa and 25% maize-75% quinoa) were also created with the help of the row numbers in plots. To determine the effects of the different plant mixtures, the ash rate, forage yield and protein yield were measured in the mid-dough stage of maize. Moreover, the dry weights of the plants and plant parts (leaf, stalk and ear) were measured on 9 different sampling dates throughout the generative period, and the relative growth rate (RGR) and crop growth rate (CGR) were calculated. As a result, some climatic factors (extreme temperatures in 2020 and extreme rainfall in June 2019) had major impacts on the RGR and CGR values. Although the amount of maize dry matter increased in almost all mixtures, quinoa performed well only in the 50% quinoa-50% maize practice. In terms of forage yield and quality, quinoa can serve as a good alternative plant in intercropping systems with maize to improve the forage quality (with higher protein yields and ash rates) without reducing the forage yield excessively.**

**Key words: Maize, quinoa, intercropping, protein yield, RGR, CGR, GDD**

## INTRODUCTION

Growing plants of more than one species in the same area at the same time is considered a sustainable agricultural technique (Bauman et al., 2002). The use of intercropping agricultural system is one of the most effective ways to increase production depending on ecological conditions. Intercropping (growing crops together) can be defined as growing more than one plant in the same area in a year (Portes et al., 2000). Studies on the subject show that this production system has important advantages in terms of increasing the efficient use of land, the efficient use of water and labor resources and inputs, ensuring compliance with ecological agriculture, and protecting the environment, in addition to increasing total production and income (Akman and Sencar, 1999; Bauman et al., 2002). Agricultural enterprises (especially in areas with limited land, labor, mechanization or capital, etc.) may prefer the intercropping production system to allow the better use of existing resources, protect soil fertility, prevent erosion, ensure weed control and use the domestic workforce more effectively (Takil et al. 2020).

Maize is the most produced plant in the world, with over one billion tons produced annually (Anonymous, 2019). It is a strategic product used as human food and in animal nutrition with seed and forage production. Moreover, maize is compatible with conventional agricultural practices, and the mechanization of all processes (planting, intermediate hoeing, irrigation, fertilization, etc.) is suitable to ensure maize production with high seed numbers and biomass per unit area (Koca, 2009). Although maize seems to require more water during the production period to ensure high biomass yields, maize needs almost the lowest amount of water among crops to produce the same dry matter per unit (Zhao and Nan, 2007). In addition to monoculture cultivation, this important plant has been utilized in intercropping practices with different plants (especially legumes) in many studies (Tiryaki et al., 2004; Armstrong et al., 2008; Ijoyah and Fanen, 2012). Some studies have reported that the crops planted with maize should be tall so that the intercropped maize (250-300 cm) is not affected by shading (Warren Wilson, 1969; Mann and Jaworski, 1970). Other studies reported that most legume plants did not perform nitrogen fixation for different reasons (chemical pollution, lack of suitable bacteria, etc.) (Ito et al., 1993; Jorgensen et al., 2004; Yılmaz et al., 2008), and since most legumes have short lengths (80 -

100 cm), the expected efficiency cannot be obtained in intercropping with maize (Awal et al., 2006).

Quinoa plants, which are suitable for different ecological conditions, can grow at different altitudes and under different soil and climatic conditions (Martinez et al. 2009). Quinoa resistant to arid and salinity conditions can survive with very low precipitation amounts, especially after the seedling period to until the end of the vegetation period. The high nutritional value of quinoa seeds has revealed that quinoa may be an alternative agricultural product that can be used for human nutrition (Takao et al., 2005). Its seeds are an extremely valuable foodstuff with high carbohydrate, quality protein, fat, fiber, vitamin and mineral contents (Yao, et al., 2015). In addition to the nutritional content of the seeds as well as some other characteristics of the plants (tall plant height (approximately 150 cm), waxy leaves (resistant to arid conditions and pests, etc.) (Geren et al., 2015; Koca et al., 2018), the plant, which has a taproot structure, stands out for its resistance to dry and salty soil conditions (Koca et al., 2017).

The quinoa plant, which has been used in many studies exploring feed quality (Geren, 2015; Tan and Temel 2018), was also used in an intercropping study (Eslami, 2016) with potato plants in recent years. However, the plant has almost never been found in any intercropping studies with maize related to growing parameters and improving feed quality. For this reason, we grew maize and quinoa plants in intercropping production systems with different plant mixtures. Thus, we tried to determine the effects of different plant mixtures on forage yield and quality as well as the effects of the plants on each other.

## MATERIAL AND METHODS

The study was carried out in the Adnan Menderes University Faculty of Agriculture Farm in western Turkey (the coastal Aegean region - Aydın province) at 37°44' N, 27°44' E and at 65 m above sea level under Mediterranean climate conditions. The SY "Fuerza" maize variety and "Turkino" quinoa variety were used as the trial materials in this study. Regarding the general characteristics of the varieties, they have features that suitable for machine harvesting and suitable for production under the main production conditions in the region.

A field experiment was established with a randomized complete block design with 4 replications during the summer production seasons in 2019 and 2020. In addition to standard practice (monocultures) that had entirely maize (100% maize) or quinoa (100% quinoa), proportional mixtures (25%, 50%, and 75%) of the two plants were used for the three other practices system. Thus, five different practices (100% maize, 100% quinoa, 25% maize-75% quinoa, 50% maize-50% quinoa and 75% maize-25% quinoa) were presented as the scope of the experiment. The plot sizes were set as 33.6 $m^2$, with 4 rows. Plant density (maize and quinoa) was set to 95238 $ha^{-1}$ (15-cm row spacing). The proportional mixture systems were arranged by adjusting the number of rows in plots with four rows. While quinoa and maize were grown in four rows in the standard practices (100% maize and 100% quinoa), the "50% quinoa-50% maize" system was created by growing two rows each of quinoa and maize. Similarly, the "75% maize-25% quinoa" and "25% maize-75% quinoa" practices were performed by growing one row of quinoa with three rows of maize and three rows of quinoa with one row of maize in the four rows.

As a result of analyzing the soil samples taken from the experimental area, the soil was determined to have a sandy loam structure, and its reaction was alkaline. In addition, the amount of organic matter in the soil was low. The results showed that when the amount of potassium was low, the amount of phosphorus was high.

The average temperature, precipitation data and the long-term average (1941-2019) values of the region (Aydın Province) during the main crop growing periods (April, May, June, July, August) in 2019 and 2020 were given in Table 1 (Anonymous, 2020). In general, it can be said that 2020 showed higher temperature values than the other study year (except in June) or the long-term average values (except in July) according to Table 1. When the precipitation values of 2020 were examined, the figures were compatible with the long-term averages (1941-2019). However, 2019 appeared to have an unstable distribution of precipitation (May was very dry, and June was extremely rainy). It can be said that 2020 was a warmer and drier year than 2019 when just the two years were considered. However, low temperature values and unstable precipitation values (fluctuating values) stood out in 2019.

**Table 1.** Temperature and precipitation values of the study in Aydın location of Turkey

| Months | Temperature (ºC) | | Precipitation (mm) | | Long term (1941-2019) | |
|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2019 | 2020 | Temperature | Precipitation |
| April | 15.8 | 16.5 | 59.2 | 43.8 | 15.9 | 48.4 |
| May | 22.4 | 23.6 | 8.3 | 40.3 | 20.8 | 35.4 |
| June | 25.6 | 24.1 | 97.7 | 8.7 | 25.5 | 15.7 |
| July | 26.6 | 27.7 | 0.2 | 1.4 | 28.1 | 7.9 |
| August | 27.2 | 28.9 | 0.0 | 0.7 | 27.6 | 6.0 |

The conventional farming practices such as fertilization, interrow hoeing, and irrigation were applied throughout the growth and development period of the studied plants. Fertilization took place in two stages. The first fertilization (safe 80 $kgha^{-1}$ N, P, and K, applied as 15-15-15 compound fertilizer) was carried out in the experimental area before sowing. Then, sowing was carried out (03.05.2019 - 25.05.2020) when the soil and weather conditions were suitable. The emergence dates of the maize plants were recorded as 10.05.2019-30.05.2020, and those of the quinoa plants were recorded as 14.05.2019-04.06.2020. A top fertilization process with urea was performed during the study period (safe 150 kgha$^{-1}$ N) from 03.06.2019-15.06.2020. The drip irrigation method was employed for irrigation.

### *Measurements*

#### *Dry weight and growing degree days (GDD)*

Periodic measurements were made in this study by taking the growth and development of the maize plants into consideration. First, 4 plants (of quinoa and maize each) that were repeatedly cut from the soil surface were taken when the maize plants reached the period of tassel removal (approximately silking). Then, one of the four plants of each species (quinoa and maize) was divided into parts (leaf, stalk and ear). All plants were dried in an oven at 70 °C for 72 hours to measure their dry weight (Perry and Compton, 1977). Therefore, the dry weights of both plant species were obtained in triplicate, and the dry weights of the plant parts (leaf, stalk and ear) were measured without repetition. After that, similar dry weight measurements (whole plant and plant parts) of the plants (quinoa and maize) were carried out 8 additional times (every week or every 7 days) until the plants reached harvest maturity (approximately the mid-dough stage of maize or the 1/4 milk line). The daily maximum and minimum temperature values were determined. Thus, the GDD values were calculated for the weekly periods. Moreover, the numbers of days at which the critical maximum temperature values (37 °C and 40 °C) were experienced in the weekly periods (Crafts-Brandner and Salvucci, 2002) were also determined. The sampling dates, calculated GDD values and the number of days that measurement of the critical temperatures for 2019 and 2020 were presented in Table 2.

**Table 2.** Sampling dates and calculated GDD values and number of days that exceed the maximum daily temperature limits (37 ºC and 40 ºC) in 2019 and 2020

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| 2019 | July 5th | July 12th | July 19th | July 26th | August 2th | August 9th | August 16th | August 23th | August 30th |
| GDD | - | 104.0 | 94.0 | 100.0 | 102.5 | 98.0 | 101.6 | 96.6 | 104.7 |
| 37 ºC | 3 | - | 1 | 3 | 3 | 3 | 1 | 5 | 19 |
| 40 ºC | - | - | - | - | - | - | - | - | - |
| 2020 | July 14th | July 21th | July 28th | August 4th | August 11th | August 18th | August 25th | September 1th | September 8th |
| GDD | - | 97.2 | 110.0 | 104.8 | 104.4 | 99.8 | 97.6 | 98.4 | 95.3 |
| 37 ºC | 1 | 4 | 5 | 1 | 4 | 2 | 1 | 2 | 20 |
| 40 ºC | - | - | 1 | - | - | - | 1 | - | 2 |

#### *Relative growth rate (RGR) and Crop growth rate (CGR)*

RGR and CGR were defined as the dry matter increase in the plant dry matter (South, 1995) and the amount of dry matter increase per unit area (m$^2$) per unit time (Loecke et al. 2004), respectively. The RGR, CGR (Hunt et al., 2002) and GDD (German et al., 1996) values obtained in our study were calculated as follows.

| | | |
|---|---|---|
| $RGR = (1/W)*(\Delta W/\Delta t)$ | $CGR = (n)*(\Delta W)/(\Delta t)$ | $GDD = [(Tmax + Tmin)/2] – Tb$ |
| W: Total dry weight of a plant (g) | Tb: 10 ºC | n: frequency (9.524/m$^2$) |
| ΔW: dry weight difference (g) between two sampling dates | Tmax: maximum daily temperature (upper limit 30 ºC) | |
| Δt: the time (days) between two sampling dates (7 days) | Tmin: daily minimum temperature (lower limit 10 ºC) | |

#### *Forage yield, protein yield and ash rate*

Harvesting was carried out (from 08.08.2019 to 27.08.2020) when the maize plants reached the dough maturity stage (1/4 milk line). The harvesting process was carried out by manually cutting the middle part of each plant from the soil surface after leaving the edge effects in the middle of each plot (8.4 m$^2$). The protein contents (values not given because of observed fluctuations) were analyzed by using NIRS-FT (Bruker MPA) with the samples. The plant samples were gathered by weighing 90 g as uniformly as possible in miniature sample cups with depths of approximately 2.8 cm and diameters of 9 cm (Gislum et al., 2004). Samples from mixed plots were analyzed, and the results were used to calculate protein yield with the formula [Protein content (%)*Dry matter yield (kg ha$^{-1}$)]. Ash was measured by igniting shredded samples from plots at 550 °C for 5 hours in a muffle furnace (SNOL 30/1300). The ash rate (provided in terms of the mineral content) was calculated by dividing the weight measured after combustion by the weight measured initially.

### *Statistical analysis*

To determine the effects of the different mixtures on the production (mixtures forage yields and protein yields and ash rate) and the growing parameters (CGR and RGR) of both the maize and quinoa plants, the values obtained from the study were analyzed statistically with a randomized block design with four replications (except for the dry weight values of the plant parts). ANOVA was applied to examine the differences among the maize and quinoa mixture practices and the interactions between the mixtures and study years. Significant differences between the means of the replications were tested using Fisher's least squares difference (LSD) method.

## RESULTS AND DISCUSSIONS

### *Forage yield, protein yield and ash rate*

The obtained fresh forage yield, protein yield and ash rate values were given in Table 3. As a result of the variance analysis, the mean square values of the measured characteristics and the significance of the differences and LSD values were given under the table. The average fresh forage yield of the experiment was determined to be 71267 kgha$^{-1}$ in the first year and 58133 kgha$^{-1}$ in the second year. In the first year, the 100% maize (91253 kgha$^{-1}$) and 75% maize-25% quinoa (89638 kgha$^{-1}$) produced higher-than-average forage yield values. In the second year, the 100% quinoa (65271 kgha$^{-1}$), 100% maize (84953 kgha$^{-1}$) and 75% quinoa-25% maize (59946 kgha$^{-1}$) produced higher than the year average. The protein yield averages were determined to be 3901 kgha$^{-1}$ in the first year and 2980 kgha$^{-1}$ in the second year. In the first year of the study, the 25% maize-75% quinoa (4226 kgha$^{-1}$), 50% maize-50% quinoa (3985 kgha$^{-1}$) and 75% maize-25% quinoa (4867 kgha$^{-1}$) produced protein yield values above the year average. The 100% quinoa (3181 kgha$^{-1}$), 25% maize-75% quinoa (3091 kgha$^{-1}$) and 75% maize-25% quinoa (3145 kgha$^{-1}$) practices of the second year showed higher values than the second-year average of the study. Considering both years together, the 25% maize-75% quinoa and 75% maize-25% quinoa come into consideration due to their high protein yield values. The ash rates were determined to be 2.45% in the first year of the study and 2.40% in the second year. Only the 100% quinoa (4.82% in the first year and 3.79% in the second year) and 75% quinoa-25% maize (2.67% in the first year and 2.71% in the second year) yielded values higher than the yearly averages both years. All other practices produced values lower than yearly averages.

**Table 3.** Means of fresh forage and protein yield and ash content

| **Years** | **2019** | | | **2020** | | |
|---|---|---|---|---|---|---|
| **Mixtures** | **Fresh forage (kgha$^{-1}$)** | **Protein yield (kgha$^{-1}$)** | **Ash (%)** | **Fresh forage (kgha$^{-1}$)** | **Protein yield (kgha$^{-1}$)** | **Ash (%)** |
| 100% quinoa | 38868 | 3001 | 4.82 | 65271 | 3181 | 3.79 |
| 100% maize | 91253 | 3427 | 1.36 | 84953 | 2555 | 1.60 |
| 25% M -75% Q | 68735 | 4226 | 2.67 | 59946 | 3091 | 2.71 |
| 50% M -50% Q | 67843 | 3985 | 1.65 | 35895 | 2929 | 2.11 |
| 75% M - 25% Q | 89638 | 4867 | 1.75 | 44598 | 3145 | 1.77 |
| **Average** | **71267** | **3901** | **2.45** | **58133** | **2980** | **2.40** |
| | **Mean Square** | | | | | |
| **Practice** | **17556472.9**** | **1361481.0**** | **10.5**** | | | |
| **Year** | **17251167.5**** | **8285177.4**** | **0.0ns** | | | |
| **practice*year** | **15003514.6**** | **949529.7*** | **0.7**** | | | |
| **LSD $_{(0,05)}$ Practice** | **440.7** | **567.0** | **0.24** | | | |

***, ****: Significant at 0.05 and 0.01 respectively, **ns:** nonsignificant, 25% M -75% Q: 25% maize-75% quinoa, 50% M -50% Q: 50% maize-50% quinoa, 75% M - 25% Q: 75% maize-25% quinoa

In both study years, the forage yield decreased in all plots in which quinoa plants were added (25% maize-75% quinoa, 50% maize-50% quinoa and 75% maize-25% quinoa). However, significant increases were observed in the two important quality parameters, protein yield and ash rate, in all plots. Specifically, the 75% maize-25% quinoa came to the forefront in terms of protein yield increase and forage yield performance in the first year, and the 25% maize-75% quinoa excelled in terms of ash rate increase and forage yield performance in the second year. Recently, the amount of forage as well as its content (quality) has gained great importance in milk and beef production (Wims et al., 2010; Åby et al., 2019). Maize is plant that have stood out for a very long time due to their high forage yields. However, maize has never fully met the needs of intensive livestock in terms of forage quality (Lemairea et al., 2014). In addition to many agricultural practices that have been developed to improve maize cultivation, such as fertilization, harvest date, plant mixtures, cutting height (Kennington et al., 2005; Walsh et al, 2008; Lentz and Ippolito 2012), intercrop production has also been performed to improve quality (Portes et al., 2000; Silva et al, 2004). Plants from many different plant groups (legumes, cruciferous plants, etc.) related to this subject have been used in production together with maize (Borghi et al., 2007; Freitas et al., 2008; Baributsa et al., 2008). In light of the data obtained from the present study, it can be said that quinoa significantly increases the quality of forage produced. This has been proven by the observed increases in the protein yields and ash rates of quinoa-intercropped plots, although the forage yield slightly decreased. The data have shown that quinoa can be a good alternative plant in intercropping systems with maize and can improve forage quality without reducing the forage yield excessively.

### *Crop growth rate (CGR)*

The CGR values calculated in this study were given in Table 4. As a result of the variance analysis, the mean square values, significances of the differences and LSD values were given under the table. The values showed that the plant mixtures had significant effects on the CGRs calculated for the maize and quinoa plants. The monoculture practices (100% maize or quinoa) were analyzed. The highest values were obtained for the third sample taken from the monoculture maize (88.9 g $m^{-2}$) and for the eighth quinoa sample (47.7 g $m^{-2}$) in the first year, and the highest values in the second year were 99.9 g $m^{-2}$ (fourth sample) for maize and 57.1 g $m^{-2}$ (eighth sample) for quinoa. The values showed a linear decrease, with the lowest values (7.0 g $m^{-2}$) obtained during the penultimate sampling of maize (eighth sample); a value of 11.5 g $m^{-2}$ (fourth sample) was obtained for quinoa in the first year. In the second year, 6.5 g $m^{-2}$ (seventh sample) and 7.5 g $m^{-2}$ (second sample) were obtained for maize and quinoa, respectively.

**Table 4.** CGR of maize (M) and quinoa (Q) in mixture practices between sampling dates in 2019 and 2020

| **CGR (g $m^{-2}$)** | | 2019 | | | | | | | | | 2020 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| 100% quinoa | Q | - | 12.4 | 20.1 | 11.5 | 24.7 | 46.0 | 33.1 | 47.7 | 26.8 | - | 7.5 | 13.3 | 50.4 | 38.7 | 51.1 | 44.1 | 57.1 | 50.3 |
| 100% maize | M | - | 82.8 | 88.9 | 70.8 | 47.3 | 39.6 | 26.2 | 7.0 | 10.2 | - | 42.5 | 50.1 | 99.9 | 62.6 | 12.4 | 6.5 | 64.8 | 56.4 |
| 50% M - 50% Q | Q | - | 13.2 | 8.5 | 17.1 | 20.7 | 38.6 | 42.6 | 18.7 | 11.4 | - | 13.3 | 19.7 | 17.7 | 39.3 | 22.4 | 50.7 | 62.0 | 62.6 |
| | M | - | 59.7 | 105.1 | 87.9 | 18.8 | 19.4 | 12.5 | 24.4 | 20.2 | - | 83.1 | 31.4 | 66.5 | 32.6 | 27.9 | 78.2 | 29.5 | 88.0 |
| 75% M - 25% Q | Q | - | 16.7 | 15.0 | 20.8 | 25.4 | 24.0 | 33.0 | 27.3 | 22.9 | - | 19.3 | 40.0 | 29.6 | 54.8 | 38.3 | 42.3 | 31.4 | 7.1 |
| | M | - | 89.9 | 58.1 | 47.2 | 89.1 | 19.7 | 25.8 | 64.4 | 83.7 | - | 86.1 | 21.1 | 90.0 | 18.1 | 41.4 | 24.9 | 16.5 | 6.8 |
| 25% M - 75% Q | Q | - | 7.3 | 10.2 | 14.0 | 58.5 | 63.4 | 53.3 | 82.6 | 63.0 | - | 29.3 | 50.3 | 23.2 | 13.4 | 31.8 | 83.6 | 81.6 | 40.3 |
| | M | - | 119.0 | 26.2 | 61.5 | 90.1 | 56.4 | 92.2 | 53.1 | 179.9 | - | 30.9 | 83.5 | 37.7 | 51.8 | 99.2 | 33.0 | 52.9 | 17.4 |
| Average | Q | - | 12.4 | 13.5 | 15.9 | 32.3 | 43.0 | 40.5 | 44.1 | 31.0 | - | 17.4 | 30.8 | 30.2 | 36.6 | 35.9 | 55.2 | 58.0 | 40.1 |
| | M | - | 87.9 | 69.6 | 66.9 | 61.3 | 33.8 | 39.2 | 37.2 | 73.5 | - | 60.7 | 46.5 | 73.5 | 41.3 | 45.2 | 35.7 | 40.9 | 42.2 |
| **Mean Square** | **practice** | | **sampling date** | | | **year** | | **practice*year** | | **sampling date*year** | | | **practice*sampling date** | | | **practice*sampling date*year** | | | |
| | 4401.8** | | 4856.0** | | | 5207.9** | | 5287.9** | | 1705.1** | | | 1867.7** | | | 4727.6 | | | |
| **LSD $_{(0,05)}$** | 7.66 | | 10.83 | | | 5.41 | | 10.83 | | 15.31 | | | 21.66 | | | 30.6 | | | |
| ⁎, ⁎⁎: Significant at 0.05 and 0.01 respectively, ns: nonsignificant, 25% M -75% Q: 25% maize-75% quinoa, 50% M -50% Q: 50% maize-50% quinoa, 75% M - 25% Q: 75% maize-25% quinoa | | | | | | | | | | | | | | | | | | | |

**Table 5.** RGR values of maize (M) and quinoa (Q) in mixture practices between sampling dates in 2019 and 2020

| **RGR (g $plant^{-1}$)** | | 2019 | | | | | | | | | 2020 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| 100% quinoa | Q | - | 0.015 | 0.021 | 0.011 | 0.021 | 0.035 | 0.020 | 0.025 | 0.012 | - | 0.007 | 0.012 | 0.041 | 0.026 | 0.027 | 0.020 | 0.023 | 0.017 |
| 100% maize | M | - | 0.077 | 0.052 | 0.031 | 0.018 | 0.013 | 0.008 | 0.002 | 0.003 | - | 0.046 | 0.041 | 0.063 | 0.031 | 0.005 | 0.002 | 0.023 | 0.017 |
| 50% M - 50% Q | Q | - | 0.028 | 0.015 | 0.028 | 0.028 | 0.043 | 0.038 | 0.013 | 0.007 | - | 0.024 | 0.031 | 0.023 | 0.043 | 0.019 | 0.038 | 0.036 | 0.030 |
| | M | - | 0.039 | 0.054 | 0.033 | 0.006 | 0.006 | 0.003 | 0.007 | 0.005 | - | 0.071 | 0.018 | 0.034 | 0.014 | 0.010 | 0.027 | 0.009 | 0.024 |
| 75% M - 25% Q | Q | - | 0.012 | 0.017 | 0.021 | 0.075 | 0.054 | 0.033 | 0.041 | 0.024 | - | 0.053 | 0.065 | 0.025 | 0.011 | 0.023 | 0.052 | 0.040 | 0.015 |
| | M | - | 0.146 | 0.016 | 0.034 | 0.040 | 0.020 | 0.028 | 0.014 | 0.042 | - | 0.023 | 0.054 | 0.018 | 0.021 | 0.036 | 0.010 | 0.014 | 0.004 |
| 25% M - 75% Q | Q | - | 0.039 | 0.027 | 0.032 | 0.031 | 0.024 | 0.030 | 0.020 | 0.015 | - | 0.030 | 0.052 | 0.028 | 0.049 | 0.025 | 0.022 | 0.014 | 0.003 |
| | M | - | 0.121 | 0.042 | 0.026 | 0.042 | 0.007 | 0.009 | 0.021 | 0.024 | - | 0.053 | 0.011 | 0.040 | 0.006 | 0.013 | 0.008 | 0.005 | 0.002 |
| Average | Q | - | 0.024 | 0.020 | 0.023 | 0.039 | 0.039 | 0.030 | 0.025 | 0.015 | - | 0.029 | 0.040 | 0.029 | 0.032 | 0.024 | 0.033 | 0.028 | 0.016 |
| | M | - | 0.096 | 0.041 | 0.031 | 0.027 | 0.012 | 0.012 | 0.011 | 0.019 | - | 0.048 | 0.031 | 0.039 | 0.018 | 0.016 | 0.012 | 0.013 | 0.012 |
| **Mean Square** | **practice** | | **sampling date** | | | **year** | | **practice*year** | | **sampling date*year** | | | **practice*sampling date** | | | **practice*sampling date*year** | | | |
| | 0.008** | | 0.005** | | | 0.01ns | | 0.009** | | 0.002** | | | 0.002** | | | 0.005** | | | |
| **LSD $_{(0,05)}$** | 0.007 | | 0.010 | | | - | | 0.021 | | 0.015 | | | 0.021 | | | 0.029 | | | |
| ⁎, ⁎⁎: Significant at 0.05 and 0.01 respectively, ns: nonsignificant, 25% M -75% Q: 25% maize-75% quinoa, 50% M -50% Q: 50% maize-50% quinoa, 75% M - 25% Q: 75% maize-25% quinoa | | | | | | | | | | | | | | | | | | | |

The CGR values calculated for the plants (quinoa and maize) in the mixture practices showed that mixtures with different plant experienced different effects (Table 4). Throughout the sampling period (nine sampling dates), sampling dates when the mixture practices CGR were greater than the general average were determined. Moreover, care was taken to ensure that the mixture practices CGR on the specified dates were also greater than 100% maize practice. The numbers indicating higher CGR for corn in 50% maize-50% quinoa was two at nine sampling dates in the first year and three at nine sampling dates in the second year. While, the numbers for quinoa were five times at nine sampling dates in the first year and three times at nine sampling dates in the second year. In 75% maize-25% quinoa, the numbers indicating higher CGR for corn were determined four at nine sampling dates in the first year, in spite of only one time at the nine dates in the second year. For quinoa, the numbers were two times at nine sampling dates in the first year and four times at nine sampling dates in the second year. In 25% maize-75% quinoa practice, the numbers indicating higher CGR of corn were five at nine sampling dates in the first year and only one time at nine sampling dates in the second year. For quinoa, the numbers were four times at nine sampling dates in the first year and two at nine sampling dates in the second year.

One of the most important reactions of plants under stress conditions is the change in CGR value due to the decrease in dry matter increase (Echarte and Tollenaar, 2006). Many studies have reported that different stress conditions (planting time, water or nutrient deficiency, insect damage, extreme temperatures etc.) affect the calculated CGR values of plants (Loomis and Connor, 1992; Ferris et al., 1998; Pandey et al., 2000; Hamidou et al., 2013). For maize, The CGR values obtained from 75% maize-25% quinoa and 25% maize-75% quinoa practices fluctuated between the years. It has been observed that the difference between the years has seriously affected maize in the practices. Even if 25% maize - 75% quinoa gave more number related to greater CGR totally, 50% maize-50% quinoa was more stable in two years. It was evaluated that the quinoa CGR was well ahead of that of the 50% maize-50% quinoa collectively. As a result of general collective evaluation, quinoa was more stable over the years in all three applications compared to maize.

### *Relative growth rate (RGR)*

The RGR values calculated in the study were given in Table 5. The results of the variance analysis and the mean squares, significances of the differences and LSD values were given under the table. The plant mixtures had significant effects on the RGR values calculated for the maize and quinoa plants. For the monoculture (100% maize), the highest RGR value for maize was obtained in the first sample in the first year by 0.077 g $plant^{-1}$ and second year by 0.046 g $plant^{-1}$ (fourth sample value was neglected). The values showed a linear decrease (except samples 4, 6 and 7 in the second year), with the lowest values (0.003 g $plant^{-1}$ and 0.017 g $plant^{-1}$ in the first and second year, respectively) obtained at the end of the years. A sudden unexpected increase in the fourth sample (0.063 g $plant^{-1}$) was observed in the second year. When the 100% quinoa was examined, the plants did not produce the highest values at the beginning (0.015 g $plant^{-1}$ in the first year and 0.007 g $plant^{-1}$ in the second year) of either year, unlike maize. The maximum value (0.035 g $plant^{-1}$) was obtained for quinoa at the sixth sampling date of the first year. In the second year, the RGRs increased until the fourth sampling date (0.044 g $plant^{-1}$), after which a lower value was obtained at the ninth sampling (0.017 g $plant^{-1}$) with a regular decrease. A sudden increase in the quinoa RGR value was observed at the fourth sampling of the second year, similar to that seen for maize.

The RGR values calculated for the plants (quinoa and maize) in the mixed practices showed that the different plant mixtures had different effects (Table 5). Throughout the sampling period (nine sampling dates), sampling dates when the mixture practices RGR were greater than the general average were determined. Moreover, care was taken to ensure that the mixture practices RGR on the specified dates were greater than 100% quinoa practice. For the corn plant, the numbers indicating higher RGR in 50% maize-50% quinoa was two times at nine sampling dates in the first year and three times at nine sampling dates in the second year. For quinoa plant, same number in the first and second years were determined to be five times at nine sampling dates. The numbers indicating higher RGR in 75% maize-25% quinoa for corn, were almost all samples (except for the third sample) at nine sampling dates in the first year and three times at nine sampling dates in the second year. The numbers for quinoa were five times in the first year and four times at nine sampling dates in the second year. The numbers indicating higher RGR obtained from 25% maize-75% quinoa for corn, in spite of four times in the first year, was determined just one time at the nine sampling dates in the second year. For quinoa, same number indicating higher CGR in the first and second years was determined to be three times at nine sampling dates. As a result of the collective evaluation of the plant mixtures, 75% maize-25% quinoa practice can be recommended for maize. Moreover, it was determined that quinoa had good performance in the 50% maize-50% quinoa practice, similar to that seen for the CGR.

The CGR and RGR values in the two years were evaluated together, the highest RGR and CGR values calculated for quinoa plants were obtained in the 50% maize-50% quinoa. Since the RGR and CGR are related to changes in dry matter per unit time (Levy and Veilleux 2007; Rykaczewska, 2013), it can be said that quinoa was less competitive or more relaxed (stress-free) in the 50% maize-50% quinoa mixture. While the 75% maize-25% quinoa gave the highest RGR values for maize plants, the 25% maize-75% quinoa gave the highest CGR values throughout the period. Moreover, the general average CGR calculated for quinoa (33.5 g $m^{-2}$) was lower than that calculated for maize (53.5 g $m^{-2}$), while the general average quinoa RGR (0.028 g $plant^{-1}$) was slightly higher (0.027 g $plant^{-1}$). The results suggested that the plant density used in this study might be slightly too high for maize, because the difference that basically separates RGR and CGR values is the plant frequency. The first-year averages of both the CGR (48.8 g $m^{-2}$) and RGR (0.029 g $plant^{-1}$) values were greater than those obtained for the second year (43.1 g $m^{-2}$ and 0.026 g $plant^{-1}$). It has been reported that temperature increases, to some extent, cause increased plant growth parameters (especially RGR) (Tollenaar, 1989; Soldati et al. 1999). Table 1 shows that the second year was warmer and drier than the first year.

Moreover, it was observed that the number of days at which critical temperatures (37 °C and 40 °C) were reached was higher in the second year than in the first year (Table 2). Net photosynthesis was inhibited at leaf temperatures above 38 °C. Phosphoenolpyruvate carboxylase, which is related to plant physiological events such as anaplerotic metabolism, pH regulation, and stomatal opening, plays a key role during C4 photosynthesis activity and decreases dramatically at leaf temperatures above 40 °C (Crafts-Brandner and Salvucci, 2002). The high CGR and RGR values obtained for the first year can be explained by the fact that the plants were exposed to less stressful conditions. Probably, it could be considered that the extreme a rainy June (97.7 mm) in the first year had a positive effect on the CGR and RGR.

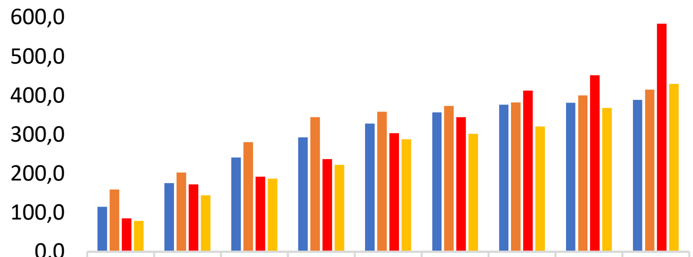
### *Dry matter weight*

The plants (maize and quinoa) dry matter values obtained from the different plant mixtures were given in Figure 1. At the beginning of the sampling period (when the maize plants were approximately silking stage), the maize weights in the 100% maize, 50% maize-50% quinoa, 25% maize-75% quinoa and 75% maize-25% quinoa practices were determined to be 114.9 g, 159.2 g, 85.2 g, 78.7 g in the first year and 95.9 g, 123.2 g, 142.6 g, 167.0 g in the second year, respectively. In both study years, the 100% maize showed high stalk (81.3 g and 38.6 g in the first and second study years, respectively) and leaf (46.6 g and 49.9 g in the first and second study years, respectively) weights, but almost negligible ear weight values (4.1 g and 10.0 g in the first and second study years, respectively) in the beginning of the sampling periods. Maize developing in 50% maize-50% quinoa at the beginning was faster than the other mixtures practices in both years. The leaf, stalk and ear weights were determined to be 71.6 g, 69.9 g and 19.8 g, respectively, in the first year and 50.1 g, 66.8 g and 5.6 g, respectively, in the second year. Different results were obtained for the 75% maize-25% quinoa and 25% maize-75% quinoa practices between the two years. The stalk, leaf and ear values were determined to be 33.6 g, 29.6 g and 7.5 g (in the 75% maize-25% quinoa practice), respectively, and 35.6 g, 44.7 g and 7.1 g (in the 25% maize-75% quinoa practice), in the first year, and 47.3 g, 137,1 g and 13.1 g (75% maize-25% quinoa), respectively, and 43.0 g, 92.6 g and 11.8 g (25% maize-75% quinoa), in the second year. At the end of the growth period (approximately mid-dough stage or 1/4 milk line), the maize weights obtained for the 100% maize, 50% maize-50% quinoa, 25% maize-75% quinoa and 75% maize-25% quinoa practices were 388.8 g, 414.9 g, 583.7 and 429.9 g, respectively, in the first year and 386.3 g, 444.5 g, 441.2 g, 391.0 g in the second year. The ear values (211.6 g and 221.3 g in the first and second year, respectively) increased very rapidly, while the stalk (103.7 g and 112.4 g) and leaf (88.6 g and 103.8 g) value increases were more limited in the 100% maize practice. If we evaluated the mixtures together, in the 50% maize-50% quinoa practice, the leaf, stalk and ear weights were determined to be 110.6 g, 125.6 g and 169.6 g, respectively, in the first year and 122.5 g, 13.5 g, 228.6 g in the second year. The leaf, stalk and ear values in 75% maize-25% quinoa practice were 116.5 g, 125.6 g, and 166.6 g, respectively, in the first year and 101.0 g, 104.8 g, and 196.3 g, respectively, in the second year. The leaf, stalk, and ear values in the 25% maize-75% quinoa changed to 176.7 g, 157.7 g, and 266.5 g, respectively, in the first year and 86.7 g, 100.5 g, and 251.4 g in the second year. At the end of the growing period, although there were some differences in plant parts, the total dry weight of maize increased in all of the mixtures in which quinoa was added (the 50% maize-50% quinoa, 25% maize-75% quinoa and 75% maize-25% quinoa practices).

The quinoa weights at the beginning of the study periods were determined to be 89.7 g, 49.2 g, 59.1 g, and 45.7 g in the first year and 112.4 g, 57.7 g, 57.5 g, and 68.2 g in the second year in the 100% maize, 50% maize-50% quinoa, 25% maize-75% quinoa and 75% maize-25% quinoa practices, respectively. The 100% quinoa showed stalk values of 60.0 g and 49.7 g in the first and second study year, respectively, and leaf values of 33.0 g and 65.3 g in the first and second study year, respectively. No ear values were determined in the first sampling. Accordingly, the quinoa parts in the 50% maize-50% quinoa were measured at 27.4 g and 20.3 g (stalk and leaf, respectively) at the beginning of sampling dates in the first year. In the second year, these values changed to 29.7 g and 25.5 g. The leaf, stalk and ear weights of quinoa in the 75% maize-25% quinoa were 14.5 g, 19.6 g and 7.6 g, respectively, at the beginning of sampling in the first year and 22.6 g, 30.2, and 9.3 g, respectively, in the second year. In the 25% maize-75% quinoa, the quinoa stalk and leaf values were determined to be 23.6 g and 27.6 g, respectively, at the beginning of sampling in the first year and 28.7 g and 37.6 g, respectively, in the second year. The ear values were not measured. At the end of the growth period, the quinoa weights obtained from the 100% quinoa, 50% maize-50% quinoa, 25% maize-75% quinoa and 75% maize-25% quinoa practices were 253.2 g, 174.8 g, 318.1 g and 181.8 g, respectively, in the first study year and 342.0 g, 269.2 g, 317.3 g, and 261.2 g, respectively, in the second study year. The quinoa ear weights (123.5 g and 101.3 g) increased very rapidly, but the stalk (55.0 g and 101.8 g) and leaf (80.6 g and 156.0 g) weight values showed more limited increases (except the second-year stalk values) in the 100% quinoa. The weight values obtained in the last sampling period of the 50% maize-50% quinoa were determined to be 31.5 g (leaf), 30.5 g (stalk), 109.0 g (ear) in the first year, and the same measurements obtained values of 103.3 g, 101.8 g, and 101.3 g in the second year. In the 75% maize-25% quinoa, the leaf, stalk and ear values were determined to be 72.5 g, 64.9 g, and 63.6 g, respectively, in the first year and 113.5 g, 60.6 g, and 76.6 g, respectively, in the second year. In the 25% maize-75% quinoa, the leaf, stalk and ear values were found to be 176.7 g, 157.7 g, and 266.5 g, respectively, in the first year and 86.7 g, 100.5 g, and 251.4 g in the second year. The development of quinoa plants in the 75% maize-25% quinoa and 25% maize-75% quinoa practices decreased more than in the 100% quinoa in both study years.

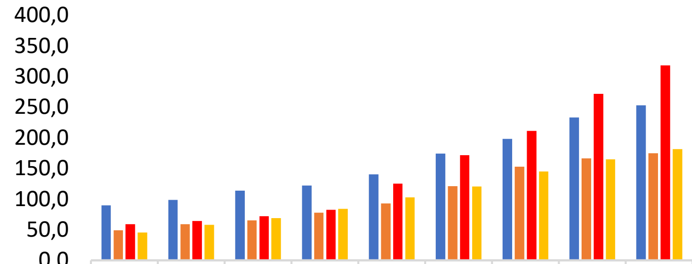
| Years | Maize | Quinoa |
|---|---|---|
| 2019 | see below | see below |
| 2020 | see below | see below |

**2019 – Maize**



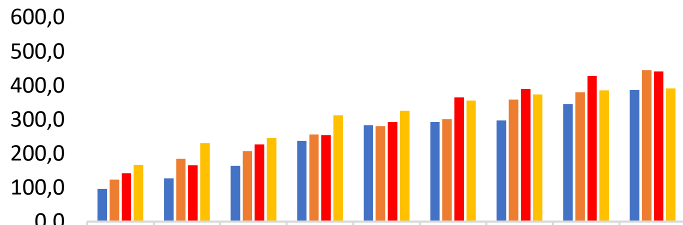

| | July 5th | July 12th | July 19th | July 26th | Agust 2th | Agust 9th | Agust 16th | Agust 23th | Agust 30th |
|---|---|---|---|---|---|---|---|---|---|
| 100% M. | 114,9 | 175,7 | 241,1 | 293,1 | 327,9 | 357,0 | 376,2 | 381,3 | 388,8 |
| 50% M - 50% Q | 159,2 | 203,0 | 280,3 | 344,9 | 358,7 | 373,0 | 382,2 | 400,1 | 414,9 |
| 25% M - 75% Q | 85,2 | 172,7 | 192,0 | 237,2 | 303,4 | 344,8 | 412,6 | 451,6 | 583,7 |
| 75% M - 25% Q | 78,7 | 144,8 | 187,5 | 222,2 | 287,6 | 302,1 | 321,1 | 368,4 | 429,9 |

**2019 – Quinoa**



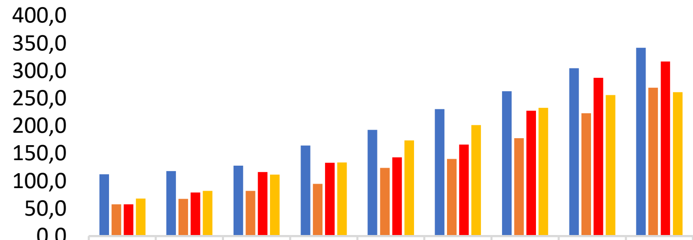

| | July 5th | July 12th | July 19th | July 26th | Agust 2th | Agust 9th | Agust 16th | Agust 23th | Agust 30th |
|---|---|---|---|---|---|---|---|---|---|
| 100% Q. | 89,7 | 98,8 | 113,6 | 122,1 | 140,2 | 174,1 | 198,4 | 233,4 | 253,2 |
| 50% M - 50% Q | 49,2 | 58,9 | 65,1 | 77,7 | 93,0 | 121,4 | 152,7 | 166,4 | 174,8 |
| 25% M - 75% Q | 59,1 | 64,5 | 72,0 | 82,3 | 125,3 | 171,9 | 211,1 | 271,8 | 318,1 |
| 75% M - 25% Q | 45,7 | 58,0 | 69,0 | 84,3 | 103,0 | 120,7 | 144,9 | 164,9 | 181,8 |

**2020 – Maize**




| | July 14th | July 21th | July 28th | Agust 4th | Agust 11th | Agust 18th | Agust 25th | Septenber 1th | Septenber 8th |
|---|---|---|---|---|---|---|---|---|---|
| 100% M. | 95,9 | 127,1 | 163,9 | 237,3 | 283,3 | 292,5 | 297,3 | 344,9 | 386,3 |
| 50% M - 50% Q | 123,2 | 184,2 | 207,3 | 256,2 | 280,2 | 300,7 | 358,1 | 379,8 | 444,5 |
| 25% M - 75% Q | 142,6 | 165,3 | 226,6 | 254,3 | 292,4 | 365,3 | 389,6 | 428,4 | 441,2 |
| 75% M - 25% Q | 167,0 | 230,3 | 245,8 | 311,9 | 325,2 | 355,6 | 373,9 | 386,1 | 391,0 |

**2020 – Quinoa**




| | July 14th | July 21th | July 28th | Agust 4th | Agust 11th | Agust 18th | Agust 25th | Septenber 1th | Septenber 8th |
|---|---|---|---|---|---|---|---|---|---|
| 100% Q. | 112,4 | 117,9 | 127,7 | 164,7 | 193,1 | 230,7 | 263,1 | 305,0 | 342,0 |
| 50% M - 50% Q | 57,7 | 67,5 | 81,9 | 95,0 | 123,8 | 140,3 | 177,6 | 223,2 | 269,2 |
| 25% M - 75% Q | 57,5 | 79,0 | 116,0 | 133,1 | 142,9 | 166,3 | 227,7 | 287,7 | 317,3 |
| 75% M - 25% Q | 68,2 | 82,3 | 111,7 | 133,5 | 173,7 | 201,8 | 233,0 | 256,0 | 261,2 |

25% M -75% Q: 25% maize-75% quinoa, 50% M -50% Q: 50% maize-50% quinoa, 75% M - 25% Q: 75% maize-25% quinoa

**Figure 1**. Dry matter weight (g plant$^{-1}$) measured from plant (maize and quinoa) from different plant mixture

## CONCLUSION

To determine the effects of different mixture practices (100% maize, 100% quinoa, 25% maize-75% quinoa, 50% maize-50% quinoa and 75% maize-25% quinoa) on plants (maize and quinoa) and on the products (ash content, forage and protein yields) obtained from the mixture practices, the results were given as three elements.

First, it was observed that the presence of quinoa increased the protein yield and ash rate in all the mixtures (25% maize-75% quinoa, 50% maize-50% quinoa and 75% maize-25% quinoa). However, there were some differences observed between the study years. The data showed that quinoa can be a good alternative plant in intercropping systems with maize to improve forage quality without reducing the forage yield excessively.

Second, although the first year of the study was colder than the second year, the calculated mean CGR and RGR values were higher in the first year than those calculated for the second year. This result is thought to be caused by the heat stress to which the plants were exposed for a longer period in the second year and by the rain seen in June of the first year. For similar reasons, the forage yield, protein yield and ash rate averages in the first year were also found to be high. In the second year of the study (2020), high temperatures were recorded during the summer plant production season. Even though quinoa could not increase the dry weight of leaves and stalks in periods (sampling times) dominated by high temperatures, generally, the plant and ear (seed) dry weights increased. Although quinoa is a C3 plant, it has been found to have severe temperature tolerance due to its taproot and relatively feathery leaf structure. Therefore, it is thought that quinoa may be an alternative plant to be grown in extreme temperatures of the subtropical region. In future studies, the performance of quinoa will be better perceived through testing with limited irrigation conditions (both hot and dry).

Finally, regarding the effects of the mixture of plants on plant growth, it can be said that all of the mixtures in which quinoa was added (50% maize-50% quinoa, 25% maize-75% quinoa and 75% maize-25% quinoa) experienced positive effects on maize plants, with increased dry matter yields at the end of the growing periods. Moreover, it was also determined that quinoa showed the highest performance in the 50% maize-50% quinoa, with higher RGR and CGR values as well as a small amount of dry matter increase.

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The manuscript is the second publish obtained from the maize-quinoa intercropping experiment. Effect of Quinoa-Corn Intercropping Production System on Yield and Quality of Mixture Silage" was published as a chapter 1 from the quinoa-maize experiment located in Aydın Turkey. The current study was presented as a chapter 2. The parameters evaluated in both manuscripts are different except for forage yield (green grass yield).

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