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Exploring Plastic Mulching as a Strategy for Mitigating Drought Stress and Boosting Maize Yield in the Ecuadorian Andes

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Abstract: Global food security faces a substantial risk stemming from water scarcity, particularly in regions heavily dependent on rainfall for agricultural purposes. In the Andean region, which is grappling with water scarcity, innovative and sustainable approaches are imperative for securing food sources. Plastic mulching has emerged as a potential solution to address water scarcity challenges by conserving soil moisture and optimizing growing conditions. A two-year field experiment was conducted that evaluated the efficacy of plastic mulching in preserving soil water content and reducing drought stress for maize. Two maize cultivars were grown with plastic mulching and conventional practices using a randomized completed block design with three replicates. The results demonstrated that employing plastic mulch led to a rise in the soil water content, particularly within the initial 30 cm of depth, resulting in variances of up to 4.71% humidity between the 20 and 30 cm depths. For the 2019 and 2020 evaluation years, plastic mulching elevated the volumetric water content in the first 30 cm of the soil by 8.39% and 14.18%, respectively. Additionally, it elevated the soil temperature by 1.26 °C and reduced the maize flowering time. Plastic mulching substantially enhanced the fresh corn yield, reaching a 162% increase compared to conventional plots. These findings underscore the potential benefits of plastic mulching in conserving the soil water content, alleviating drought and cold stress for crops in the Andean region.

Keywords: plastic mulching; water use efficiency; Andean region; drought; sustainable agriculture; water scarcity; climate change

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1. Introduction

Water plays a pivotal role in sustaining life and ensuring agricultural productivity. The most significant utilization of water by humans is in agriculture, far surpassing other consumptive uses [1,2]. Despite its abundance, with approximately 70% of the Earth's surface covered by water, many regions grapple with water-related challenges. With the ongoing evolution of global climate patterns, agriculture must devise resilient methods capable of adjusting to shifting climatic conditions, especially in areas susceptible to drought. Among the strategies explored to mitigate the impact of these challenges, the use of plastic mulching has emerged as a promising solution in enhancing water use efficiency, improving drought tolerance and ultimately increasing crop yields [3–5]. In this context, our study explores the implementation of plastic mulching methods as a prospective approach to cultivating food security crops, especially in regions like the Andes of Ecuador, where the availability of water is a crucial factor for maintaining sustainable agricultural production [6].

Maize (*Zea mays* L.) holds considerable agricultural importance in the Andean region, primarily due to its extensive cultivation area. It stands as the most extensively cultivated crop in the highlands of Ecuador, playing a pivotal role in securing the region's food security [7]. In addition, the maize landraces grown in the region carry significant cultural heritage, intertwined with local traditions and traditional products [8]. The predominant maize variety found in the area is soft or floury grain maize (var. *amylacea*), covering approximately 74,000 hectares, with an average dry grain yield of 1.08 t ha^{-1} and a fresh corn yield of 3.22 t ha^{-1} [9]. Despite its importance, maize production faces challenges, particularly low yields can be attributed to the crop's susceptibility to the adverse climatic conditions prevalent in the highlands, including drought and cold stress.

Plastic mulching is a common technique used in vegetable production in Asia that aims to safeguard the root systems of plants from various environmental stressors such as cold, drought, excess humidity, weeds, and pests [10,11]. This method involves covering the soil with plastic sheets to create a protective barrier. The benefits of plastic mulching in agriculture are multifaceted. During daylight, the plastic sheets absorb light energy and warm the soil [12–14]. This absorbed heat is retained at night, mitigating thermal imbalances that would otherwise hinder plant development in colder soils. Moreover, plastic impedes weed growth, enhances water use efficiency, facilitates carbon fixation, and contributes to increased organic matter in the soil [10,15]. By addressing these multiple aspects, plastic mulching has emerged as a versatile and effective strategy for optimizing agricultural productivity while mitigating the impacts of environmental stressors on crop growth.

Previous studies have highlighted the favorable outcomes associated with plastic mulching, including positive impacts on water conservation, stress mitigation, and increased crop yields. In the dryland county of Ningxia, China, an assessment of plastic mulching revealed that the use of plastic film led to enhanced soil water storage down to a depth of 2 m, resulting in a maize yield increase of up to 29% compared to conventional planting [12]. Thidar et al. [16] observed improved maize yield and root growth in the top 30 cm of soil in the arid regions of northwest China, attributing these benefits to a higher soil moisture content and reduced evaporation facilitated by plastic mulching. Similarly, in South Korea, plastic mulching demonstrated a significant enhancement in the soil moisture content during the maize cropping season, contributing to a 48% increase in maize yield [3].

Under dryland farming conditions, recent findings indicate that plastic mulching can substantially improve water use efficiency by 39.6% and increase the maize yield by 36.3% in northeast China [10]. A meta-analysis encompassing 394 studies on maize in China revealed that plastic mulching reduced the global stress-weighted water footprint per unit of output by 33.3% compared to non-mulching practices [4]. Despite the wealth of scientific reports on plastic mulching in maize cultivation from Asia [1,10], there is a notable dearth of information concerning the evaluation of this technology in the Americas, particularly in the Andean region. Consequently, a comprehensive understanding of the application and potential benefits of plastic mulching in Andean maize cultivation is still lacking.

Addressing water-related challenges in the Andean agricultural system is crucial for sustaining livelihoods and bolstering food production. The lack of irrigation infrastructure in the highlands of Ecuador amplifies the negative impact of drought on crop yield, requiring innovative and sustainable solutions to enhance water resilience in the region. Over the course of this two-year field study, two open-pollinated maize cultivars were grown during the dry season, employing both plastic mulching and a conventional non-mulching system. The objective was to assess the use of the plastic film on the soil water content, soil temperature, maize yield, and other agronomic traits in the highlands of Ecuador.

2. Materials and Methods

The field experiments were conducted at the experimental station "Santa Catalina" of the National Institute for Agricultural Research (INIAP) during the dry seasons (June to August) of 2019 and 2020. During this time, Santa Catalina experienced temperate weather throughout the year, with an average temperature of 13 °C, a minimum of 2 °C, and a maximum of 26 °C. The dry seasons' rainfall recordings were 87 mm and 153 mm for the years 2019 and 2020, respectively. The experimental site, situated at 3050 m above sea level (00°22′5.6″ S and 78°33′23″ W), shares similar environmental conditions to the highlands of the Andes where maize is typically cultivated. The soil texture is loam, characterized by a black color and Andisol type, featuring a high organic matter content (7.7%), a pH of 5.1, and nitrogen and phosphorus contents of 91 and 93 ppm, respectively. Soil preparation for planting involved one plowing pass and two harrowing passes, following regional farmer recommendations.

The study employed a randomized complete block design with three replicates to assess the agronomic impact of plastic mulching on two well-known open-pollinated maize varieties: INIAP 101 (early type) and INIAP 122 (late type). The seeds were provided by the Maize Program of INIAP. The four treatments, randomly applied within each block, included (1) INIAP 101 with plastic mulching, (2) INIAP 101 without plastic mulching (conventional practice), (3) INIAP 122 with plastic mulching, and (4) INIAP 122 without plastic mulching (conventional practice).

The experimental field was divided into three blocks of equal size (replicates), each was further divided into four experimental units (treatments) and consisted of six rows (5.0 m long) with a spacing of 0.8 m between rows. The plastic mulching was installed on beds measuring 1.40 m wide and 0.30 m high. The beds were covered with black mulching plastic film, 45 microns thick and 1.20 m wide (ReyFilm Black, REYENVAS S.A, Seville, Spain). The two central rows and the central bed formed the main plot, where a polypropylene tube (1 m in length) was buried in the center to measure the volumetric water content in the soil. The volumetric soil water content, which represents the volume of water per unit volume of soil [17] and is expressed as a percentage, was measured every three or four days during the season using a Diviner-2000 sensor (Sentek Technologies, Stepney, Australia). In addition, the soil temperature at a 0.05 m depth was monitored every three or four days, hourly during daylight, using a digital thermometer (GTH175/Pt, Greisinger, Regenstauf, Germany).

Planting was carried out manually with a plant density of 50,000 plants per hectare, with two seeds every 0.25 m along the rows and 0.80 m among rows. Thinning to one plant per site occurred 15 days after planting to ensure consistent plant density across all treatments. Fertilization was uniform across plots, with urea (46% N) applied at a rate of 140 kg ha^{-1} of nitrogen, split into three equal batches: before planting, 45 days after planting, and 70 days after planting. Phosphorous (P_2O_5) and potassium (K_2SO_4) were applied before planting at rates of 80 and 60 kg ha^{-1}, respectively. Weed control was performed manually to ensure that the experiment remained free from unwanted plants. Planting occurred on June 3 2019 and June 9 2020 at the beginning of the dry season, to ensure drought stress during the growth period. Irrigation was not applied and the plants relied on residual soil moisture from the rainy season and sporadic rains during the cycle.

The maize yield was assessed after harvesting fresh corn (only the ears, without the leaves covering the corncob) from the main plots. The plant height and female flower time were evaluated as indicated by CIMMYT [18]. The agronomic results were subjected to analysis of variance (ANOVA) and mean comparison tests (Fisher LSD, $\alpha = 0.05$) using the R statistical package [19]. The mean soil temperature and volumetric water contents were analyzed using the paired Student's *t*-test ($\alpha = 0.05$).

3. Results

3.1. Soil Water Content

Significant differences (where $p < 0.001$ was used as the threshold for significance in this study) in the volumetric soil water content were observed between plots employing plastic mulching and those following conventional practices. Throughout the dry season, the mean volumetric soil water content from the plastic mulching plots consistently exceeded that of the conventional plots, with the exception of one mean at a depth of 100 cm. The differences were most pronounced in the upper 30 cm of soil, displaying water content values ranging from 0.65% to 4.71%. During the first year of evaluation, plastic mulching increased the volumetric soil water content in the first 30 cm of depth of the soil by 14.18%, while in the second year, it increased by 8.39%. As the depth increased, the differences in water content diminished. At a depth of 100 cm, the differences were either smaller or statistically non-significant ($p > 0.01$) (Table 1).

Table 1. Mean and standard error of the volumetric soil water content (%) at various soil depths for maize subjected to drought stress with plastic mulching and conventional practices during the dry season (June–August) in the Ecuadorian highlands, 2019–2020.

Soil Depth (cm)	Year 2019				Year 2020			
	Plastic Mulching (%)	Conventional (%)	Dif. *	*p*-Value (*t*-Test) $n = 33$	Plastic Mulching (%)	Conventional (%)	Dif. *	*p*-Value (*t*-Test) $n = 30$
0–10	23.48 ± 1.48	19.97 ± 2.07	3.51	***	23.84 ± 2.23	21.11 ± 1.66	2.73	***
10–20	31.73 ± 2.14	28.62 ± 0.81	3.11	***	30.49 ± 1.41	29.84 ± 1.59	0.65	***
20–30	36.00 ± 1.09	31.29 ± 0.34	4.71	***	35.48 ± 0.72	31.91 ± 0.92	3.57	***
30–40	35.99 ± 0.7	35.07 ± 0.27	0.92	***	35.78 ± 0.53	35.22 ± 0.65	0.56	***
40–50	35.53 ± 1.09	35.01 ± 0.15	0.52	***	35.52 ± 0.55	35.36 ± 0.60	0.16	***
50–60	35.73 ± 0.43	34.95 ± 0.11	0.78	***	35.79 ± 0.56	35.27 ± 0.56	0.52	***
70–80	31.83 ± 0.28	30.46 ± 0.35	1.37	***	32.24 ± 0.60	30.87 ± 0.71	1.37	***
80–90	33.53 ± 0.82	32.93 ± 0.23	0.60	***	33.64 ± 0.45	32.95 ± 0.65	0.69	***
90–100	35.96 ± 0.36	35.46 ± 1.79	0.50	***	35.55 ± 0.39	35.66 ± 0.41	−0.11	**

Note(s): * Difference between plastic mulching and conventional practices; *p*-value = ** (<0.01) and *** (<0.001).

The accumulation of water in the soil during the maize cultivation period was notably higher in the plastic mulching plots compared to the conventional ones (Figure 1). Diviner-2000 readings revealed distinct patterns of water accumulation throughout the growth cycle. In 2019, the plastic mulching plots maintained volumetric water content values between 35% and 40% (green zone) until the early days of August (Figure 1a). In contrast, the conventional plots reached the same green zone but only until the first week of June (Figure 1b). Humidity levels between 30% and 35% (blue zone) were more prevalent in the plastic-covered plots throughout the entire crop cycle (Figure 1a), whereas in the conventionally managed plots, the prevalence was lower and persisted only until the initial days of August (Figure 1b).

Conversely, the conventionally managed plots (without plastic covers) exhibited a higher occurrence of the lowest volumetric water content values for an extended period (Figure 1b). Humidity values below 20% (orange and red zones) began to manifest in the conventional plots in early June (Figure 1b), 30 days after maize planting. In contrast, in the plastic mulching plots, these values began to appear in the initial days of August (Figure 1b), 60 days after planting. The results obtained in 2019 closely mirrored those observed in 2020 (Figure 1c,d).

3.2. Soil Temperature

The mean temperature observed in the plots utilizing plastic mulching exceeded the temperature recorded in the conventional plots. Throughout both evaluated years, notable statistically significant differences ($p < 0.01$) were evident between the temperatures recorded in the plastic mulching plots and those in the conventional plots. Plastic mulching elevated the average soil temperature by 1.26 °C at a depth of 5 cm (Table 2). These temperature variations were more pronounced during the early hours of the day, whereas around midday, they tended to converge, as illustrated in Figure 2.

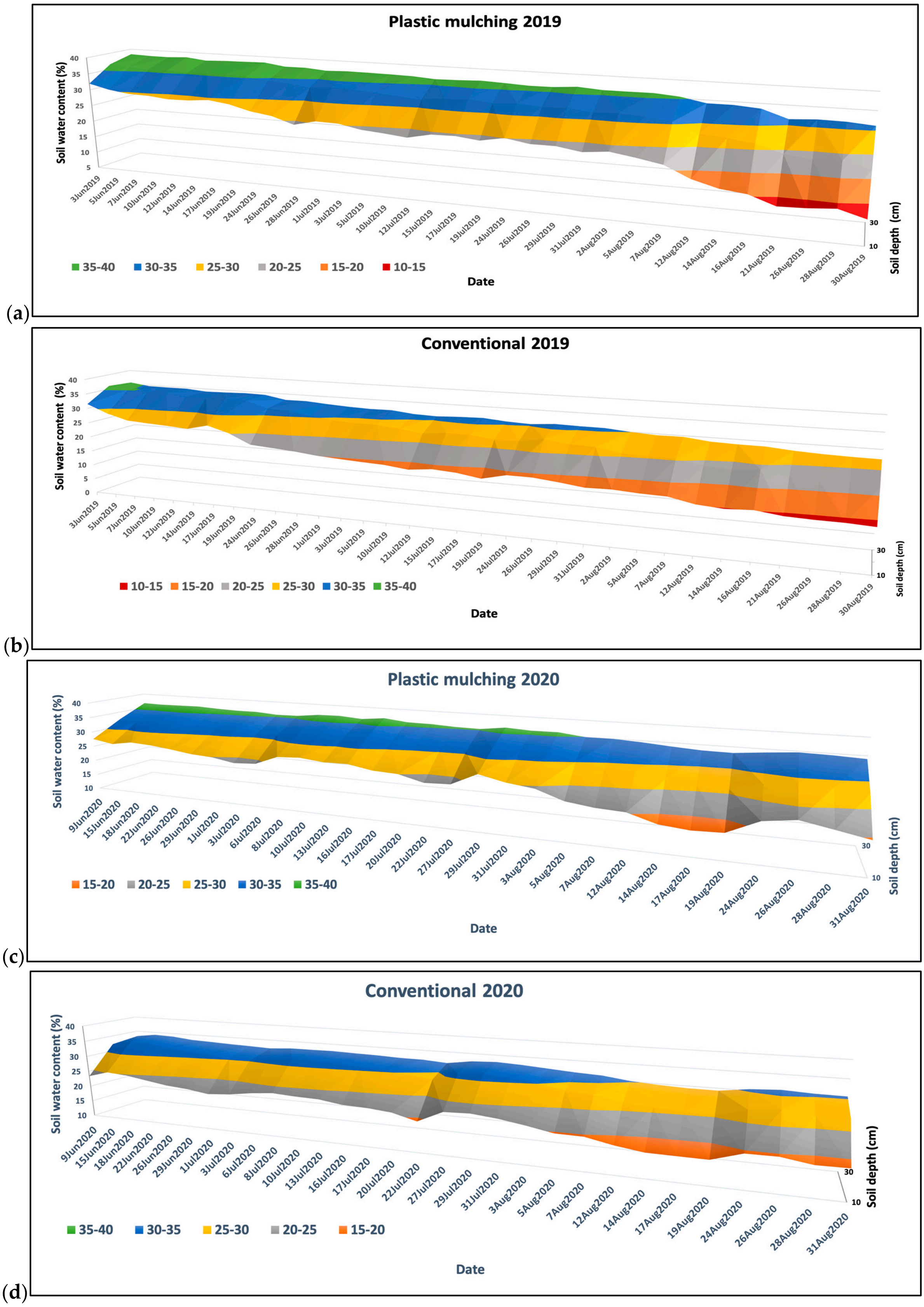
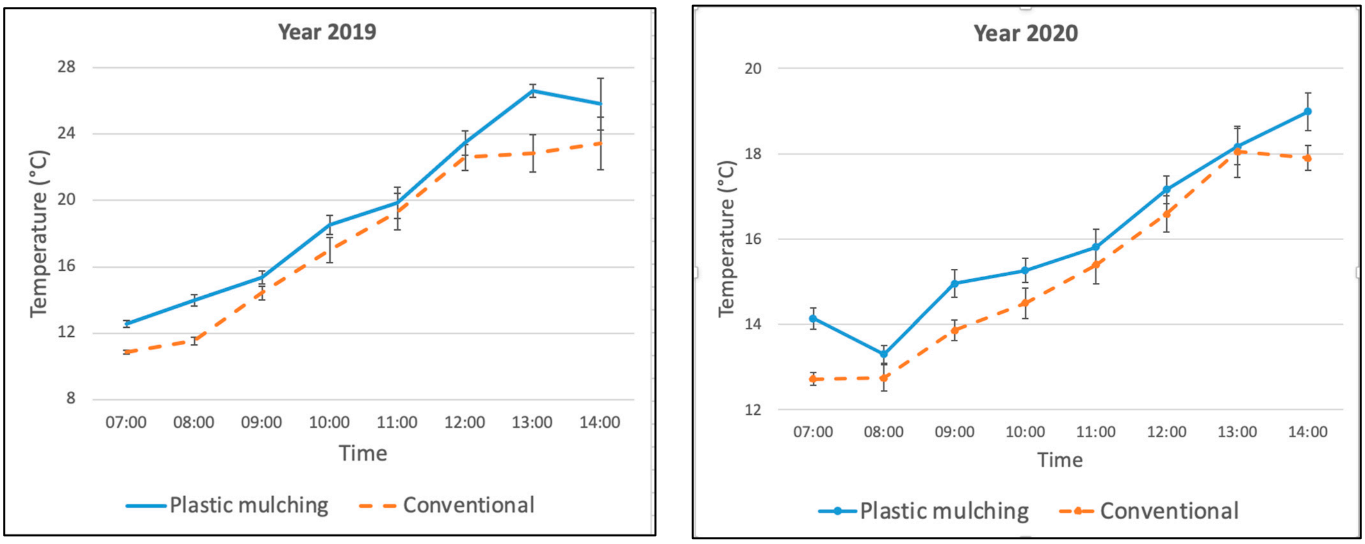


Figure 1. Accumulated volumetric soil water content (%) in the upper 30 cm of soil for Andean maize cultivation during the dry season using two planting systems: (**a**) plastic mulching 2019; (**b**) conventional growing 2019; (**c**) plastic mulching 2020; and (**d**) conventional growing 2020.

Table 2. Mean and standard error of the soil temperature (°C) at a 5 cm depth for Andean maize cultivated with plastic mulching and the conventional planting method during the dry season (June–August) in the Ecuadorian highlands, 2019–2020.

Planting Method	Mean, Year 2019 °C	Mean, Year 2020 °C	Average °C
Plastic mulching	17.91 ± 0.65	16.05 ± 0.34	16.98
Conventional	16.30 ± 0.77	15.13 ± 0.35	15.72
n	143	84	-
p-Value (*t*-test)	***	***	-
Difference	1.61	0.92	1.26

Note(s): *p*-value = *** (<0.001).



(**a**) (**b**)

Figure 2. Hourly variation of the soil temperature at a 5 cm depth during Andean maize cultivation using plastic mulching and conventional management: (**a**) results from 2019 and (**b**) results from 2020.

3.3. Agronomic Performance of Maize

Significant statistical differences were detected in the yield between the treatments employing plastic mulching and conventional practices for both evaluated varieties ($p < 0.01$). In the case of INIAP 101, plastic mulching led to a notable increase in the average yield of fresh ears, rising from 3.12 to 6.24 t ha^{-1} in 2019 and from 2.32 to 7.49 t ha^{-1} in 2020. Similarly, for INIAP 122, the yield rose from 1.20 to 3.79 t ha^{-1} in 2019 and from 4.73 to 6.50 t ha^{-1} in 2020 with the use of plastic mulching. Furthermore, statistically significant differences were evident in the female flowering time between plastic mulching and the conventional planting practice. Plastic mulching accelerated the female flowering time in both varieties, reducing the duration from 164 to 129 days and from 138 to 118 days in INIAP 101 for 2019 and 2020, respectively. Likewise, for INIAP 122, the duration decreased from 177 to 145 days in 2019 and from 146 to 129 days in 2020. Regarding plant height, an increase in plant size was observed in both varieties in the plastic mulching plots, with statistically significant differences in 2020 ($p < 0.01$) but not in 2019 ($p > 0.01$) (Table 3). Overall, the use of plastic mulching accelerated growth and the development of more robust plants during the dry season under drought conditions in the highlands of Ecuador.

Table 3. Mean and standard error of various agronomic traits in Andean maize cultivated under water stress conditions with two planting systems during the dry season (June–August) in the highlands of Ecuador, 2019–2020.

Maize Variety	Planting System (T)	Yield, Fresh Ears (t ha^{-1})		Female Flowering Time (Days after Planting)		Plant Height (m)	
		Year 2019	Year 2020	Year 2019	Year 2020	Year 2019	Year 2020
INIAP 101	Plastic mulching	6.24 ± 0.98	7.49 ± 0.22	129.00 ± 1.53	118.00 ± 1.15	1.87 ± 0.10	2.16 ± 0.09
	Conventional	3.12 ± 0.72	2.34 ± 0.63	164.00 ± 1.73	138.00 ± 1.15	1.75 ± 0.23	1.64 ± 0.02
INIAP 122	Plastic mulching	3.79 ± 0.84	6.50 ± 0.70	145.67 ± 2.91	129.00 ± 1.00	2.07 ± 0.07	2.08 ± 0.05
	Conventional	1.20 ± 0.34	4.73 ± 0.25	177.67 ± 4.33	146.33 ± 0.88	1.64 ± 0.02	1.77 ± 0.05
ANOVA, p-value (T)		***	***	***	***	*	***
LSD * value (T)		1.42	0.78	4.76	1.35	0.26	0.14
Coefficient of variation (%)		28.05	10.50	2.19	0.73	9.87	5.31

Note(s): p-value = * (<0.05) and *** (<0.001).

4. Discussion

Water in the soil plays a crucial role in sustaining food production. Soil water acts as the primary reservoir from which plant roots extract water via transpiration. Additionally, soil water assumes a pivotal role in the carbon and nitrogen cycles, integral to the biological activities of the planet [2]. Water scarcity exerts a significant threat to global food security, particularly in regions where agriculture is highly dependent on rainfall. The detrimental impacts of drought and unpredictable weather patterns are progressively affecting crop yields, further complicating the challenges linked to poor nutrition. In the context of the Andean region, where farmers face the dual challenge of water scarcity and malnutrition, innovative and sustainable approaches are imperative for ensuring food security [6]. Reducing farmers' vulnerability to climate change is a key aspect of improving our knowledge of how water behaves in the soil under diverse farming techniques.

The current study explored the potential of plastic mulching as a viable strategy to enhance the soil water content for crop production, focusing on its application in marginal areas of the Andean region, where drought and cold are common threats to farming. Increases in the severity and frequency of drought in a warming climate may negatively impact agricultural production and food security. Previous studies have estimated the agricultural impacts of climate conditions, such as low precipitation and soil moisture deficits. These conditions were found to decrease the average annual yield by 25–45% compared to more favorable wet growing seasons [20,21].

Our investigation revealed that the application of plastic mulching effectively conserved more soil water during drought conditions (Figure 1 and Table 1). Plots utilizing plastic mulching exhibited an increased water content of up to 4.7% on average in the upper soil layers (0–10, 10–20, and 20–30 cm), which coincide with the primary maize root zones. Notably, the highest water content readings, reaching up to 35–40%, were sustained for a dry period of 60 days in the plots with plastic mulching (Figure 1). These results are consistent with a previous investigation carried out in Iraq, indicating that the use of plastic mulching improved the soil's ability to retain water, leading to decreased evaporation from the soil surface. The study observed soil water content levels reaching up to 40% in the 0–10 cm layer and up to 31% in the 10–20 cm layer [22]. This consistency in results affirms that plastic mulching effectively mitigates soil water evaporation and augments soil water retention in the upper layers, not only in an Asian context [3,16,23,24] but also in the highlands of the Andean region.

Studies conducted in Asia and Africa have demonstrated that the cultivation of maize using plastic mulch results in enhanced grain yield and improved water use efficiency, attributed to increased soil moisture and soil thermal conditions [25–27]. However, the applicability of this technology in maize in the Americas and particularly in the Andean region, characterized by cold conditions and limited water for irrigation, remained unexplored [1]. In the current research, a statistically significant increase ($p < 0.001$) was observed in crop yield when utilizing plastic mulch. Specifically, there was a remarkable improvement of 162% for INIAP 101 and 73% for INIAP 122 compared to the conventional plots, highlighting the potential benefits of adopting plastic mulching practices in addressing the challenges posed by climate-induced conditions in the Andean region. Conventionally managed plots yielded between 1.20 and 4.73 t ha^{-1}, near the national average of 3.22 t ha^{-1} [9]. Plastic mulching mitigated the effects of drought by preserving greater soil moisture for extended periods, resulting in yields ranging from 3.79 to 7.49 t ha^{-1} (Table 3, Figure 1).

In this experiment, planting during the dry season was a deliberate choice to subject the maize plants to water stress, allowing them to assess the impact of plastic mulching under drought conditions. In the highlands of Ecuador, where sporadic rains between June and August are insufficient for maize cultivation, profitability relies on the availability of irrigation. In the years 2019 and 2020, 87 and 153 mm of rain, respectively, was recorded during the crop growth period from June to August, falling short of the 500 mm well-distributed minimum requirement for the profitable production of maize [28]. Both plastic-mulched and non-mulched maize plants exhibited signs of drought stress, resulting in lower yields than under conventional well-watered growing conditions.

The notable increase in maize yield observed in plots with plastic mulching can be attributed to the soil's enhanced moisture retention, particularly within the first 30 cm of depth (Table 1 and Figure 1). Additionally, the higher soil temperature, averaging 1.26 °C higher than that recorded in the conventional plots (Table 2 and Figure 2), played a significant role in increasing yield. The combination of an increased soil water content and a higher temperature contributed to stress reduction, resulting in improved vegetative development manifested by greater yield, increased plant height, and a reduction in days to female flowering time (Table 3). The flowering time in maize is sensitive to thermal units or growing degree days (GDD) because it is a heat-driven process. Maize plants require a certain amount of accumulated heat to progress through their growth stages [29]. Consequently, the utilization of plastic mulching emerges as an effective cultivation system for the highlands of the Andes, enhancing soil moisture and facilitating root water absorption, ultimately bolstering maize production in environments susceptible to drought and cold stress. These findings align with results reported in northeast China, where plastic mulching increased the maize yield by improving the soil moisture content in the first 30 cm of soil (up to 11% more than the control without plastic mulch), thereby enhancing root development [16]. The substantial average yield increase of 117% over two years of the current evaluation surpasses the average increase reported in a meta-analysis conducted in China, encompassing 266 studies on maize production with plastic mulching, which recorded an average increase of 24.32% [30]. Other studies have reported maize yield increases of 71.77% [5] and 47.68% [31]. Surprisingly, despite the rise in yield, plastic mulching did not uniformly enhance the plant height (Table 3). The assessment in 2019 revealed no statistically significant differences in plant height, whereas significant variances were observed in 2020 ($p < 0.001$). A study carried out by Hashin and colleagues [31] similarly found that the application of plastic mulching did not have a significant impact on plant height across various crops.

As mentioned before, plastic mulching offers several mechanisms of action that contribute to increased water use efficiency and enhanced crop yields, including weed suppression, reduced soil compaction, improved nutrient availability, and enhanced microbial activity. Herein, we discussed those related to soil moisture conservation and soil temperature regulation since we demonstrated, across two years, that plastic mulching increased the soil water content and soil temperature in maize grown in the Andean region. Plastic mulch creates a physical barrier that reduces the evaporation of water from the soil surface. This helps to retain moisture within the root zone, thus minimizing atmospheric water loss. In addition, the impermeable nature of plastic mulch prevents water runoff, allowing the soil to absorb and retain more water. Plastic mulch also absorbs and retains solar radiation, raising soil temperature. This warming effect is advantageous for early-season crops and in cooler climates, promoting faster germination and plant growth. Moreover, plastic mulch acts as an insulator, preventing extreme temperature fluctuations in the soil and promoting the root development of certain crops. These results could benefit farmers in a broader context, across different environmental conditions and crop types. Yield increases and economic benefits have been reported for other field crops, such as potatoes and wheat [32,33].

A potential limitation associated with the adoption of plastic mulching in the Andean region is its elevated cost. In Ecuador, a 900-m roll was acquired for USD 160, serving two production cycles. Estimations suggest that planting one hectare of maize would necessitate eight rolls, totaling USD 1280 for two production cycles. The increase in maize yield obtained by the use of plastic mulching during two years (Table 3) would justify the investment, with an average additional estimated income of USD 615 ha^{-1} (Supplementary Table S1). This analysis did not take into account the supplementary expenses associated with plastic installation, nor did it factor in the potential savings related to weed control and crop hilling. A detailed economic evaluation of this technology fell beyond the scope of this study, as it was conducted under stress conditions that impeded the realization of the crop's potential yield. Assessing plastic mulching under normal conditions, devoid of drought, is imperative to ascertain the maize yield potential. Nonetheless, in China, various studies have highlighted economic advantages for maize farmers. Zhang et al. [12] reported a two-year average net income increase of USD 236 ha^{-1} compared to the no-plastic control and another study documented higher net profits ranging from USD 49 to 217 ha^{-1} compared to conventional management [15].

Despite its advantages in soil water conservation, water use efficiency, yield increase, and economic returns, plastic mulching in agriculture comes with certain drawbacks. The persistent use of plastic films can contribute to environmental pollution, as these materials are non-biodegradable and can accumulate in agricultural soils over time. Additionally, the improper disposal or burning of plastic films can release harmful pollutants into the air and soil, further exacerbating environmental degradation [11,34,35]. These negative impacts emphasize the need for sustainable alternatives and proper waste management strategies to mitigate the environmental consequences associated with plastic mulching in agriculture. Fortunately, as science and technology evolve, biodegradable plastic mulches generated from maize [36], cassava [37], and other plants are now available on the market. These products are already being evaluated and could contribute to reducing the drawbacks of plastic films [38,39].

Further research is needed in the Andean region to assess the benefit and impact of this technology. Plastic mulching could be used in a biodiverse production scheme, including crop rotation, crop association, crop for service, and a reduction in agrochemicals (herbicides and fertilizers) to increase the sustainability of the system. Engaging farmers in research will help to clarify the potential impact of plastic mulching in the region. This research could be particularly beneficial in areas with irregular rainfall, water scarcity, and low temperatures.

5. Conclusions

The use of plastic mulching increased soil water content, especially within the initial 30 cm of depth by up to 14.18%. Additionally, plastic mulching elevated the soil temperature by 1.26 °C and reduced the maize flowering time. Under drought conditions, plastic mulching substantially boosted the fresh corn yield by up to 162% in comparison to the traditionally managed plots, with an average additional estimated income of USD 615 ha^{-1}. Plastic mulching not only facilitated effective soil water conservation but also enhanced crop productivity, offering a potential solution to mitigate the impact of drought and address malnutrition within local communities.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/w16071033/s1. Supplementary Table S1. Economic benefit of the use of plastic mulching in maize grown during the dry season (June–August) in the highlands of Ecuador, 2019–2020.

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