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Potentiality of Soil Mulch and Sorghum Extract to Reduce the Biotic Stress of Weeds with Enhancing Yield and Nutrient Uptake of Maize Crop

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Abstract

Two field trials were conducted in 2018 and 2019 to develop practical and economically efficient weed control programs in corn. The experiment included six treatments (cowpea, rice straw, sorghum extract, hoeing, foramsulfuron herbicide and weedy check). The treatments were arranged in randomized complete block design with four replicates. Findings showed that reduction in total weed number was evident with application of hoeing, cowpea and rice straw in 2018 and 2019 seasons, in addition to foramsulfuron herbicide and sorghum extract in 2019. Cowpea, hoeing, foramsulfuron herbicide and rice straw recorded higher reduction in dry biomass of grassy weeds in both seasons. Reductions in N, P and K uptake by weeds because of rice straw and cowpea treatments were similar to hoeing treatment in both seasons. The increases in ear grain weight and grain yield ha^{-1} due to cowpea and hoeing treatments were similar to rice straw one. In 2019 season, cowpea treatment was the superior practice for improving N, P and K uptake of maize, significantly leveling hoeing for K uptake. The values of gross returns and benefit/cost ratio of cowpea and sorghum extract, respectively, were higher than rice straw application. In conclusion, cowpea as a live mulch achieved acceptable weed control in maize by reducing weeds growth and lowering their ability to deplete the soil nutrients. Also, cowpea treatment improves growth and yield of maize with better utilization of nutrients. Thus, cowpea could be exploited as an eco-friendly method of weed management programs in maize cultivation.

Keywords Allelopathy · Maize yield · Nutrient uptake · Biotic stress · Weeds

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Potenzial von Bodenmulch und Sorghumextrakt zur Reduzierung des biotischen Stresses durch Unkräuter bei gleichzeitiger Steigerung des Ertrags und der Nährstoffaufnahme von Mais

Zusammenfassung

Zur Entwicklung praktisch anwendbarer und ökonomisch effizienter Unkrautbekämpfungsprogramme bei Mais wurden in den Jahren 2018 und 2019 zwei Feldversuche durchgeführt. Das Experiment umfasste sechs Behandlungen (Augenbohne, Reisstroh, Sorghumextrakt, Hacken, Foramsulfuron-Herbizid und Unkrautcheck). Die Behandlungen wurden in einem randomisierten vollständigen Blockdesign mit vier Wiederholungen durchgeführt. Die Ergebnisse zeigten, dass die Gesamtzahl der Unkräuter durch die Anwendung von Hacken, Augenbohne und Reisstroh in den Saisons 2018 und 2019 deutlich reduziert wurde, zusätzlich zu Foramsulfuron-Herbizid und Sorghumextrakt im Jahr 2019. Augenbohne, Hacken, Foramsulfuron-Herbizid und Reisstroh verzeichneten in beiden Saisons eine höhere Reduktion der Trockenbiomasse von grasartigen Unkräutern. Die Verringerung der N-, P- und K-Aufnahme durch Unkräuter aufgrund der Behandlungen mit Reisstroh und Augenbohne war in beiden Jahreszeiten ähnlich wie beim Hacken. Die Erhöhungen des Ährengewichts und des Kornertrags ha^{-1} durch die Behandlungen mit Augenbohne und Hacken waren ähnlich wie die mit Reisstroh. In der Saison 2019 war die Augenbohne-Behandlung die überlegene Methode zur Verbesserung der N-, P- und K-Aufnahme von Mais, wobei sie das Hacken bei der K-Aufnahme deutlich übertraf. Die Werte der Bruttoerträge und des Nutzen/Kosten-Verhältnisses von Augenbohne bzw. Sorghumextrakt waren höher als bei der Anwendung von Reisstroh. Zusammenfassend lässt sich sagen, dass die Augenbohne als lebender Mulch eine akzeptable Unkrautkontrolle bei Mais erreicht, indem sie das Wachstum von Unkraut reduziert und dessen Fähigkeit, die Bodennährstoffe zu entziehen, verringert. Außerdem verbessert die Behandlung mit der Augenbohne das Wachstum und den Ertrag von Mais bei besserer Ausnutzung der Nährstoffe. Somit könnte die Augenbohne als umweltfreundliche Methode für Unkrautbekämpfungsprogramme im Maisanbau genutzt werden.

Schlüsselwörter Allelopathie · Maisertrag · Nährstoffaufnahme · Biotischer Stress · Unkräuter

Introduction

Maize (*Zea mays* L.) ranks worldwide as one of the most distinguished cereal crops due to its high-yielding potential and productivity. As maize occupies vast cultivated area with yielding millions of tons of grain per year worldwide, it is considered a cash crop. Other than the ecological variables, the most significant challenge to maize yield and consequently economic benefits is competition from weeds (Karimmojeni et al. 2010). Weeds not only compete with crop plants for environmental resources, but also often disserve normal plant growth through releasing prejudicial allelochemicals into the rhizosphere (Khaliq et al. 2010). Moreover, weeds are regarded as sanctuary for many pests, i.e. insects and diseases causing damages to crop (Dangwal et al. 2010). Accordingly, weeds considerably occur biotic stress on crop plants (Saudy 2013). Because of weed competition, maize yield was reduced by 30.5–67.7% (El-Metwally et al. 2009; Abd El-Samad et al. 2012).

Currently, there are various approaches can be used to control weeds in maize fields. Herbicides application considered the most rapid and efficacious action among all the available weed control methods (Santos 2009). However, the use of herbicides causes serious threats associated with environmental and human health issues and weed resistance (Walker et al. 2013; Dallali et al. 2017). The matter becomes more difficult in organic agriculture systems, as the use of chemicals (e.g. herbicides) is prohibited. Otherwise, hoeing as a manual-mechanical tool is effective for controlling weeds (Saudy 2013), however, it is time consuming and became not widely applicable due to limited labor and high cost. Hand-weeding and mechanical weed control patterns are alternatives to herbicides with greatly increased cost and relatively low efficacy (Boyd and Brennan 2006). Attempts are still being made by researchers to find safe and low-cost solutions, considering the environmental and health concerns. Moreover, the most sanguine blueprint to substitute synthetic herbicides is to use eco-friendly natural plant compounds. In this regard, allelopathy as a natural and an environment-friendly approach for weed control can improve crop yields, decrease the use of synthetic pesticides, and maintain the ecosystems (Hegab et al. 2008). Allelopathy presents a significant and sustainable tactic for biologically weed management (Arora et al. 2015) by release of chemical substances from various plant parts which ultimately affect the normal growth of other plants (Delcour et al. 2015). Herbicide application rate can be reduced by up to 68%, in combination with sorghum water extracts, for efficient weed control in maize (Khan et al. 2012).

Because maize plants are grown in relatively wide distances, open land spaces become abundant. Open land areas allow weeds to grow well and compete with crop plants for growth resources. Living mulches are cover crops can be intercropped between the rows of a main crop filling the uncovered spaces (Monaco et al. 2002), suppressing weed growth. Use of cover crop is considered important for improving the competitiveness of crops against weeds and preventing yield losses in maize (Saudy 2015). Intercropping cowpea as a living mulch with maize achieved reductions in weed biomass amounted to 39.6–45.5% (Jamshidi et al. 2013).

The process of covering the soil by natural or synthetic materials before or after planting called mulching. Straw mulch can also offer a good method of decreasing weed emergence and growth (Duppong et al. 2004). Reductions in weed density and weed dry weight with approximately 60.0% of weed control efficiency were achieved because of organic mulch application (Yadav et al. 2015). Thus, different crop yields were improved by about 80–135% due to application of mulch (Lekasi et al. 2001; El-Metwally and El-Wakeel 2019). Rice straw mulch increased potato tuber yield by 48.9% (Bhullar et al. 2015).

The relative efficiency of the abovementioned methods for weed control requires more studies to determine the best among them. Subsequently, providing the weed control programs with distinctive low cost and safe tool, particularly in organic systems. Thus, the current study aimed to compare between several means having different mechanisms of weed control based on their efficiency in combating weeds and improving maize crop returns.

Materials and Methods

Experimental Site

At the Research and Experimental Station Farm, Faculty of Agriculture (30°19′ N, 31°16′ E), Ain Shams University at Shalakan, Kalubia Governorate, Egypt, a field experiment was conducted during two successive seasons of 2018 and 2019. The soil of the research site was clay and its properties are presented in Table 1. According to US Soil Taxonomy (Soil Survey Staff 1999), the soil is order Entisols and suborder Fluvents. Moreover, some meteorological data of the study location (air temperature, relative humidity and solar radiation) are illustrated in Fig. 1. Maize was cultivated after harvesting of Egyptian clover (*Trifolium alexandrinum*, L.) in both seasons.

Procedures

Grains of maize cultivar Single-Cross-128 (white) were sown on May 16 and 2 in 2018 and 2019, respectively (1–2 grains per hill) with 25-cm distance on one side of ridge, and then sowing irrigation was applied. At 25 days after sowing (DAS), plants were thinned to secure one plant per hill followed by irrigation. Phosphorus fertilizer (ordinary calcium super phosphate, 15.5% P_2O_5), at a rate of 36 kg P ha^{-1}, was broadcasted during the soil preparation. Nitrogen (N) fertilizer as urea (46.5%N) at a rate of 192 kg N ha^{-1} was applied into two equal portions, 25 and 42 DAS just before irrigations.

Experimental Treatments and Design

The experiment contained selected six practices involved in controlling weeds, in maize, as follows:

i. Cowpea (planted as live mulch) treatment: Maize and cowpea (cv. Balady) were sown simultaneously on the same ridge, each crop on a side of the two-ridge sides, with 25 cm-hill distance and two plants per hill of cowpea,
ii. Rice straw treatment (dead mulch): At 25 DAS, dead straw of rice at rate of 8.0 ton ha^{-1} was applied as a layer of about 5–6 cm thickness, covering the whole plot surface except maize plants,
iii. Sorghum extract treatment: An amount of 200 g of dry sorghum residues was grinded, then soaked overnight in an alcohol-water solution (850 ml ethanol, 85%, and 150 ml distilled water), at ambient condition (25 °C ± 2). The extract was obtained by filtering the mixture through a Whatman #1 filter paper. This filtrate was designated as a stock solution for the aqueous extract of sorghum having 100% concentration. From the stock solution, a solution of 1200 mg L^{-1} was prepared for field application,
iv. Hoeing treatment: Hand hoeing was practiced twice, 21 and 42 DAS,

Table 1 Physical and chemical properties of the soil at the Research and Experimental Station Farm, Shalakan district, Kalubia Governorate, Egypt

Physical property			Chemical property					
Sand %	Silt %	Clay %	pH	EC ($dS\ m^{-1}$)	OM %	Available nutrient ($mg\ kg^{-1}$)		
						N	P	K
18.91.22	25.94 ± 0.43	55.15 ± 0.42	7.82 ± 0.10	2.53 ± 0.15	1.31 ± 0.09	112 ± 2.10	6.44 ± 0.23	413 ± 4.42

The composite soil sample was obtained from nine sub samples, 0–30 cm depth, before sowing; pH: soil acidity, *EC* electrical conductivity, *OM* organic matter, *N* nitrogen, *P* phosphorus, *K* potassium

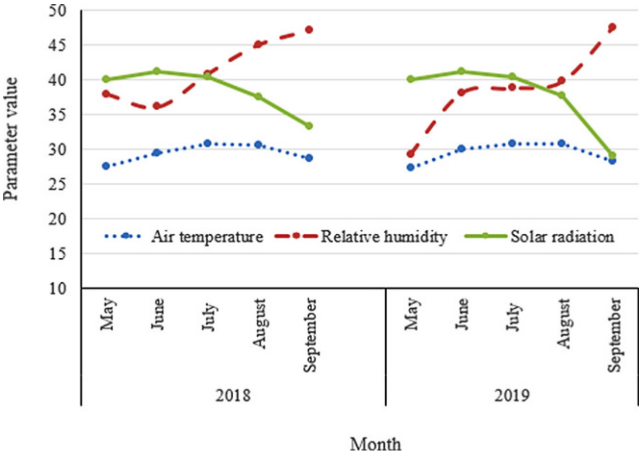

Fig. 1 Averages of air temperature (°C), relative humidity (%) and solar radiation (MJ $m^{-2}day^{-1}$) in 2018 and 2019 seasons at the Research and Experimental Station Farm, Faculty of Agriculture, Ain Shams University, Kalubia Governorate, Egypt

v. Foramsulfuron treatment: Foramsulfuron herbicide, Equip® 22.5 OD, Bayer CropScience, Italy (2-(N-((4,6-imethoxypyrimidin-2-yl) carbamoyl) sulfamoyl)-4-formamido-N,N-dimethylbenzamide) at a rate of 1.8 L ha^{-1} was sprayed as post-emergence, 25 DAS,

vi. Weedy check treatment (control): Herein, weeds were left to grow freely throughout the growing season of maize.

The above six practices were allocated in a randomized complete block design with 4 replicates using the mathematical model shown in formula 1. The experimental unit (plot) size was 12.6 m^2 containing 5 ridges each of 3.6 m length and 0.7 cm width. Each of sorghum extract and foramsulfuron herbicide were separately sprayed using a manual back-pack knapsack sprayer fitted with a flat-fan nozzle and calibrated to deliver 476 L water ha^{-1}.

$$Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij} \qquad (1)$$

where:

Y_{ijk} is response, μ is an overall mean effect, τ is the treatment, β is the block effect, and ε_{ij} is error.

Assessments

Weeds

Based on the survey of the dominant weeds at the experimental site through the two growing seasons, the abundant weed flora is shown in Table 2. Weeds were hand pulled from one square meter of each plot at 60 DAS to estimate the number of broad leaf, grassy and total weeds. Thereafter, weeds were air-dried (for 10 days) and oven-dried (at 70 °C till reaching constant weight), then the dry biomass weight of each group was recorded.

Table 2 Abundant weed flora associated maize plants during 2018 and 2019 growing seasons at the Research and Experimental Station Farm, Shalakan district, Kalubia Governorate, Egypt

Common name	Latin name	Abundance %	
		2018	2019
Broad leaf weeds			
Common purslane	*Portulaca oleracea*	17.1 ± 3.40	47.6 ± 2.14
Malta jute	*Chorchorus olitorius*	6.4 ± 1.76	–
Grassy weeds			
Jungle rice	*Echinochloa colonum*	14.5 ± 4.37	52.4 ± 2.14
Barnyard grass	*Echinochioa crus-galli*	62.0 ± 6.83	–

Maize

At 65 DAS, four guarded maize plants were randomly chosen within each plot to measure each of plant height, leaf area index and leaf greenness (SPAD). SPAD value of the fourth leaf was determined by chlorophyll meter (SPAD-502Plus) according to Süß et al. (2015).

At maturity, maize plants were harvested (on September 21 and 2 in 2018 and 2019 seasons, respectively). Sample of ten guarded plants was taken from one middle ridge of each plot for measuring ear traits (length, width, weight and grain weight/ear) and weight 100 grains. Ear and grain yields ha^{-1} were estimated using ears of the rest plants of the middle ridges in the plot. Grain yield ha^{-1} was calculated based on 13% moisture content.

Nutrients Uptake

Nitrogen (N), phosphorus (P) and potassium (K) contents of weed plants and maize grains were estimated according to Cottenie et al. (1982). Furthermore, nutrient uptake was computed separately by multiplying nutrient content by dry biomass of total weeds and grain yield of maize.

Economic Evaluation

According to Cimmyt (1988), the economic evaluation was estimated by calculating the cost of cultivation for different agro-inputs, i.e. labors, fertilizers, irrigation, insect control, harvesting, and other necessary experimental requirements.

Returns of each tested treatment were calculated ($ ha^{-1}) on the basis of local market price as follow:

$$\text{Gross returns} = \text{Grain yield} \times \text{price of maize yield}\,\text{ha}^{-1}\left(\$\,\text{ha}^{-1}\right) \tag{2}$$

$$\text{Net return} = \text{Gross returns} - \text{cost of treatment}\left(\$\,\text{ha}^{-1}\right) \tag{3}$$

$$\text{Benefit/Cost (B/C) ratio} = \frac{\text{Gross return from treatment}}{\text{Total cost of treatment}} \tag{4}$$

The average prices were taken from the local market ($200 per ton of maize grains).

Data Analysis

A 2-way analysis of variance (ANOVA), for the data of the two seasons, was performed (Casella 2008), using Costat software program, Version 6.303 (2004). Means separation was performed only when the F-test indicated significant ($p < 0.05$) differences among the treatments, using Duncan's multiple range test (alphabetical letters).

Results

Effect of Weed Control On Weeds

Weed Density

Regarding the weed density expressed in number of weed plants, ANOVA exhibited that the tested weed control treatments had significant impacts on number of broad leaf weeds, grassy weeds and total weeds associated with maize plants in 2018 and 2019 growing seasons (Table 3). All applied treatments reduced total weed number compared to weedy check. Rice straw, hoeing and sorghum extract in 2018 and 2019 seasons, in addition to foramsulfuron herbicide and cowpea in 2019 season, showed the maximum reduction in broad leaf weed number. Moreover, grassy weeds were less abundant with using hoeing, cowpea and rice straw in 2018 and 2019 seasons. However, total weed number was lower because of hoeing, cowpea and rice straw in 2018 and 2019 seasons, in addition to application of foramsulfuron herbicide and sorghum extract in 2019.

Weed Biomass

As illustrated in Table 3, rice straw (in 2018 and 2019 seasons) as well as foramsulfuron herbicide, hoeing sorghum extract and cowpea (in 2019 season) were the effective treatments for reducing the dry biomass of broad leaf weeds. On the other hand, cowpea, hoeing, foramsulfuron herbicide and rice straw recorded the higher reductions in dry biomass of grassy weeds in both growing seasons. All applied weeded treatments statistically equaled in suppressing

Table 3 Number and dry biomass weight of weed flora associated maize plants as affected by weed control treatments in 2018 and 2019 seasons

Variable	Broad leaf weeds		Grassy weeds		Total weeds	
	2018	2019	2018	2019	2018	2019
Number m^{-2}						
Cowpea	30.0 ± 5.29^{a}	42.0 ± 26.15^{b}	14.0 ± 2.58^{d}	16.0 ± 7.30^{b}	44.0 ± 4.90^{cd}	58.0 ± 24.68^{b}
Rice straw	3.0 ± 1.91^{c}	9.0 ± 5.74^{b}	25.0 ± 9.85^{cd}	15.0 ± 7.00^{b}	28.0 ± 11.55^{d}	24.0 ± 9.38^{b}
Sorghum extract	11.2 ± 3.45^{bc}	12.0 ± 12.00^{b}	64.0 ± 11.78^{b}	80.0 ± 31.62^{ab}	75.2 ± 14.83^{b}	92.0 ± 38.26^{b}
Hoeing	10.0 ± 3.83^{bc}	32.0 ± 22.21^{b}	13.0 ± 3.79^{d}	33.0 ± 12.48^{b}	23.0 ± 7.00^{d}	65.0 ± 31.51^{b}
Foramsulfuron	19.0 ± 6.81^{ab}	0.0 ± 0.00^{b}	48.0 ± 8.16^{bc}	76.2 ± 25.93^{ab}	67.0 ± 13.00^{bc}	76.2 ± 25.93^{b}
Weedy check	27.5 ± 4.50^{a}	108.0 ± 21.73^{a}	89.6 ± 9.24^{a}	119.0 ± 31.47^{a}	117.2 ± 8.46^{a}	227.0 ± 52.34^{a}
Biomass (g m^{-2})						
Cowpea	36.9 ± 3.26^{bc}	8.7 ± 6.81^{b}	18.1 ± 1.07^{c}	36.9 ± 6.10^{c}	54.9 ± 5.69^{b}	45.6 ± 12.36^{bc}
Rice straw	8.2 ± 5.04^{c}	7.7 ± 6.90^{b}	54.9 ± 20.77^{bc}	13.3 ± 6.30^{c}	63.1 ± 24.78^{b}	20.9 ± 10.66^{c}
Sorghum extract	22.5 ± 9.22^{bc}	5.3 ± 5.35^{b}	76.2 ± 11.03^{b}	171.5 ± 58.81^{ab}	98.7 ± 8.29^{b}	176.8 ± 61.88^{b}
Hoeing	28.2 ± 13.29^{bc}	6.2 ± 3.29^{b}	19.7 ± 5.63^{c}	50.1 ± 16.82^{c}	48.0 ± 9.41^{b}	56.2 ± 19.30^{bc}
Foramsulfuron	23.6 ± 12.28^{bc}	0 ± 0.0^{b}	46.2 ± 5.83^{bc}	86.2 ± 29.60^{bc}	69.8 ± 13.63^{b}	86.2 ± 29.60^{bc}
Weedy check	51.2 ± 3.69^{a}	114.2 ± 19.57^{a}	130.8 ± 17.79^{a}	259.1 ± 31.70^{a}	182.0 ± 19.64^{a}	373.3 ± 31.41^{a}

Means within columns followed by different letters are significantly different at $P < 0.05$

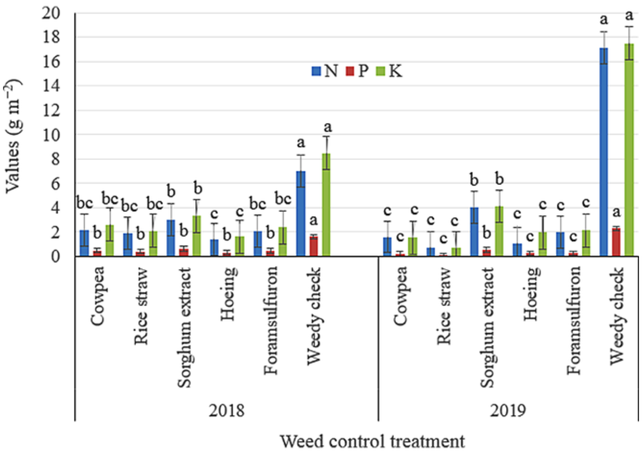

Fig. 2 Nutrient uptake of total weeds associated maize plants as affected by weed control treatments in 2018 and 2019 seasons. Columns with various letters refers to significant differences at 0.05 level of probability

weeds, reducing the dry biomass of total weeds surpassing the weedy check.

Nutrient Uptake by Weeds

Significant reductions in N, P and K uptake by weed plants were obtained in weeded treatments compared to unweeded (weedy check) ones in 2018 and 2019 seasons (Fig. 2). Reductions in N, P and K uptake by weeds in plots received rice straw or intercropped with cowpea as living mulch were as similar as those hoed twice in both seasons. In 2018 season, the differences between sorghum extract and each of cowpea, rice straw and foramsulfuron herbicide were not significant in this respect.

Effect of Weed Control On Maize

Maize Growth

Maize growth traits i.e. plant height, LAI and SPAD reading were significantly responded to weed control treatments (Table 4). Generally, hoeing was the distinctive practice for enhancing the aforementioned growth traits in 2018 and 2019 seasons. However, the differences between such superior treatment and each of cowpea, rice straw and sorghum extract (for plant height in 2018); cowpea and foramsulfuron herbicide (for plant height in 2019); cowpea, rice straw and foramsulfuron herbicide (for LAI and SPAD in 2019) as well as cowpea, rice straw, sorghum extract and foramsulfuron herbicide (for SPAD in 2018) were not significant.

Maize Yield and Yield Attributes

All yield and yield attributes of maize were significantly enhanced due to application of weed control treatments in both seasons of 2018 and 2019 compared to the weedy check (Table 5). In this regard, weeded practices (cowpea, rice straw, sorghum extract, hoeing, foramsulfuron herbicide) were statistically similar and more effective in improving all yield traits, except both cowpea for ear weight and sorghum extract for weight of 100 grains in 2018 season. In 2019 season, cowpea and hoeing were the most effective treatments for enhancing all yield traits. Also, in 2019 season, the improvements owing to cowpea and hoeing were as similar as rice straw and sorghum extract (for ear width and ear weight) as well as rice straw (for grain weight of ear and grain yield ha^{-1}).

Nutrients Uptake by Maize Plants

Weed control treatments showed remarkable effects on N, P and K uptake by maize (Fig. 3). Herein, rice straw along with sorghum extract, cowpea and hoeing induced higher uptake of N and P in 2018 season. Also, foramsulfuron herbicide, rice straw and sorghum extract were the effective treatments for capturing more K. In 2019 season, cowpea treatment was the superior practice for improving N, P and K uptake, significantly leveled hoeing for K uptake.

Table 4 Plant height, leaf area index (LAI) and leaf chlorophyll content (SPAD) of maize as affected by weed control treatments in 2018 and 2019 seasons

Variable	Plant height (cm)		LAI		SPAD	
	2018	2019	2018	2019	2018	2019
Cowpea	235.6 ± 4.99^{ab}	259 ± 4.47^{ab}	775.9 ± 21.5^{bc}	785.2 ± 11.7^{ab}	51.9 ± 1.83^{a}	44.8 ± 1.97^{ab}
Rice straw	230.5 ± 7.66^{ab}	237.9 ± 4.87^{bc}	779.1 ± 33.3^{bc}	735.4 ± 18.2^{ab}	52.1 ± 1.15^{a}	47.7 ± 0.43^{a}
Sorghum extract	231.1 ± 7.54^{ab}	228.9 ± 6.72^{c}	727.6 ± 33.4^{c}	679.7 ± 58.6^{b}	49.5 ± 1.49^{a}	42.6 ± 2.83^{b}
Hoeing	248.4 ± 4.38^{a}	263.2 ± 1.34^{a}	892.8 ± 32.8^{a}	826.5 ± 64.7^{a}	51.7 ± 1.07^{a}	43.4 ± 1.33^{ab}
Foramsulfuron	217.0 ± 13.27^{b}	246.6 ± 10.46^{abc}	805.4 ± 24.0^{b}	752.5 ± 18.8^{ab}	50.8 ± 2.72^{a}	44.2 ± 0.57^{ab}
Weedy check	222.9 ± 9.05^{b}	187.8 ± 11.72^{d}	653.5 ± 2.5^{d}	498.9 ± 57.0^{c}	47.2 ± 0.35^{b}	31.6 ± 2.46^{c}

Means within columns followed by different letters are significantly different at $P < 0.05$

Table 5 Ear traits and yields of maize as affected by weed control treatments in 2018 and 2019 seasons

Variable	Ear traits				Weight of 100 grains (g)	Yields (t ha^{-1})	
	Length (cm)	Width (cm)	Weight (g)	Grain weight (g)		Ear	Grain
2018							
Cowpea	21.9 ± 0.34^{a}	6.27 ± 0.11^{ab}	180.7 ± 12.43^{b}	146.0 ± 10.30^{a}	35.3 ± 2.05^{ab}	14.6 ± 0.70^{ab}	11.6 ± 0.51^{ab}
Rice straw	22.4 ± 0.61^{a}	6.20 ± 0.15^{ab}	199.7 ± 9.99^{a}	158.5 ± 8.63^{a}	33.9 ± 2.35^{ab}	15.8 ± 1.15^{ab}	12.4 ± 0.87^{ab}
Sorghum extract	21.8 ± 0.69^{a}	6.12 ± 0.08^{ab}	208.2 ± 10.30^{a}	166.5 ± 8.01^{a}	27.7 ± 2.48^{b}	17.1 ± 0.76^{a}	13.6 ± 0.74^{a}
Hoeing	22.7 ± 0.50^{a}	6.35 ± 0.25^{a}	197.2 ± 9.06^{a}	151.2 ± 7.17^{a}	34.0 ± 1.25^{ab}	16.9 ± 0.74^{a}	12.9 ± 0.66^{a}
Foramsulfuron	22.7 ± 0.08^{a}	6.15 ± 0.12^{ab}	204.0 ± 6.84^{a}	148.2 ± 1.44^{a}	38.9 ± 3.77^{a}	16.9 ± 0.74^{a}	12.8 ± 0.55^{a}
Weedy check	20.2 ± 0.84^{b}	5.75 ± 0.24^{c}	152.7 ± 14.53^{c}	124.0 ± 11.61^{b}	22.4 ± 1.26^{c}	11.4 ± 1.00^{c}	8.6 ± 0.80^{c}
2019							
Cowpea	24.6 ± 0.59^{ab}	6.48 ± 0.11^{a}	297.0 ± 10.28^{a}	213.1 ± 6.63^{a}	36.8 ± 1.41^{a}	24.9 ± 0.96^{a}	11.80 ± 0.58^{a}
Rice straw	23.2 ± 0.23^{bc}	6.28 ± 0.11^{a}	253.0 ± 9.68^{ab}	179.8 ± 3.83^{ab}	32.3 ± 1.06^{b}	20.6 ± 0.81^{bc}	9.84 ± 0.28^{ab}
Sorghum extract	21.9 ± 1.19^{cd}	6.20 ± 0.14^{ab}	220.7 ± 25.18^{bc}	156.1 ± 17.43^{bc}	31.4 ± 2.40^{b}	18.0 ± 2.12^{c}	8.24 ± 0.94^{bc}
Hoeing	25.4 ± 0.31^{a}	6.43 ± 0.10^{a}	285.0 ± 3.80^{a}	182.8 ± 23.67^{ab}	37.7 ± 0.85^{a}	23.9 ± 0.38^{ab}	11.06 ± 0.94^{a}
Foramsulfuron	21.2 ± 0.88^{d}	5.80 ± 0.01^{b}	179.2 ± 16.76^{c}	128.6 ± 12.67^{c}	30.2 ± 1.07^{b}	14.8 ± 1.50^{d}	7.10 ± 0.54^{c}
Weedy check	19.1 ± 0.78^{e}	5.33 ± 0.21^{c}	137.9 ± 17.37^{d}	98.8 ± 10.23^{d}	27.6 ± 0.52^{c}	10.1 ± 1.73^{e}	5.87 ± 0.72^{d}

Means within columns followed by different letters are significantly different at $P < 0.05$

Economic Returns

The economic analysis showed that chemical weed control using foramsulfuron herbicide was the cheapest practice with maximum benefit/cost ratio, while hoeing achieved the highest gross and net returns (Table 6). However, the lowest net return was obtained with application of foramsulfuron herbicide. Except for the traditional weed control practices in maize (hoeing and foramsulfuron), cowpea and sorghum extract recorded higher values of net returns and benefit/cost ratio, respectively, comparing to rice straw.

Discussion

Undoubtedly, weeds represent severe biotic stress toward crop plants, especially at early growth stages. Thus, treatments which can quench weed growth early are considered more effective practices in this respect. The present study offers several safe weed control patterns which may have different mechanisms for suppressing weeds in maize.

Common weed control practices i.e. hoeing (as a mechanical method) and foramsulfuron herbicide (as a chemical one) achieved high efficiency in weed elimination, reducing number, weight (Table 3) and nutrient uptake of weeds (Fig. 2). In this concern, hoeing leads to tearing and/or uprooting weeds, reducing their competition toward crop plants. Higher efficiency of hoeing in removing weeds enabled crop plants to make good use of environmental resources; thus, increasing the competitiveness of maize plants against weeds (Abd El-Samad et al. 2012). In addition to its efficient weed control, hoeing improves soil structure, aeration, water penetration and the availability of some nutrients for crop plants. Consequently, improvements in maize growth (Table 4), yield and its components (Table 5) and nutrient uptake (Fig. 3) are expected to be achieved. Weed control efficiency reached 90.6% with 50.9% increase in grain yield of maize due to hoeing application (Saudy 2013). Also, nutrient availability and utilization were enhanced with hoeing treatment (Saudy et al. 2020). However, although hoeing is still a traditional weed control in row crops, manual labor has become scarce and expensive.

Foramsulfuron is a sulfonylurea herbicide inhibits acetolactate synthase (ALS), the key enzyme in the biosynthesis pathway of branched-chain amino acids valine, leucine and isoleucine in chloroplasts (Yu et al. 2010). Such herbicide controls many grassy and some broad leaf weeds in maize, but it is more efficient against grasses and sedges weeds than broadleaf ones. By illustrating the data in Table 3 in 2018 season, foramsulfuron herbicide caused reductions amounted to 30.9 and 46.4% as well as 53.9 and 64.7% in number and dry weight of broad leaf and grassy weeds, respectively. The average control provided by foramsulfuron herbicide at the four- to five-leaf growth stage was 71.0% of *Echinochloa oryzoides* and 62.0% of *Echinochloa phyllopogon* (Damalas et al. 2012). However, the widespread use of ALS-inhibiting herbicides led to rapid selection of many resistant weed populations. ALS-resistant weeds represent the fastest-growing group of herbicide-resistant weeds worldwide, with 159 monocot and dicot related weed species (Heap 2018). So, reliance on herbicides should be reduced and substitutional tools of weed control should be applied (Papapanagiotou et al. 2019).

Based on the obtained findings of the current study, covering soil surface whether with live mulch (planting

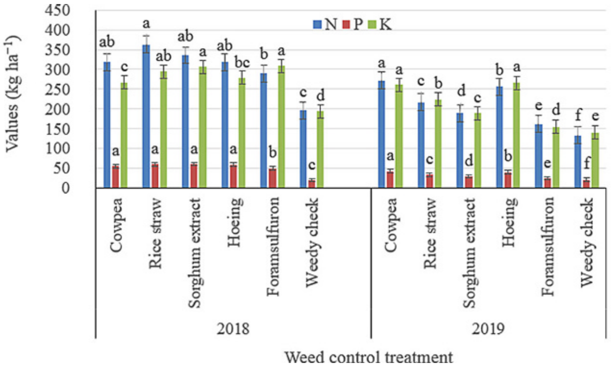

Fig. 3 Nutrient uptake of maize as affected by weed control treatments in 2018 and 2019 seasons. Columns with various letters refers to significant differences at 0.05 level of probability

Table 6 Economic evaluation of maize yield as affected by weed control treatments

Treatment	Cost of treatment ($ ha^{-1})	Gross returns ($ ha^{-1})	Net returns of treatment ($ ha^{-1})	Benefit/Cost ratio
Cowpea	113.3	2340.0	2226.7	20.7
Rice straw	184.0	2224.0	2040.0	12.1
Sorghum extract	80.0	2184.0	2104.0	27.3
Hoeing	160.0	2396.0	2236.0	15.0
Foramsulfuron	53.3	1990.0	1936.7	37.3

cowpea as a smother crop) or dead mulch (as rice straw) achieved noticeable reduction in weed number and dry biomass (Table 3) and NPK uptake by weeds (Fig. 2). It is well known that weed competition increase when crops (such as maize) planted in widely-spaced rows. This situation, allows a high portion of ambient light to penetrate (in addition to increase the completion with crops for other growth resources, i.e. soil nutrients, soil water, and CO_2). This helps the undesirable plants (weeds) to growth well. However, rapid closure of the vegetative canopy of cultivated plants over weeds decreases sunlight and thus directly limits weed growth. Furthermore, limited light on the soil surface can reduce subsequent germination and growth of weed seeds (Monaco et al. 2002). In this respect, the mechanism of covering soil mainly depends on blocking light to reach weeds growing beneath crop canopy. It was hypothesized that as the density of the living mulch increased, canopy closure occurred more rapidly, decreasing the amount of photosynthetically active radiation (PAR) available beneath the crop canopy (Jamshidi et al. 2013). Moreover, living mulches suppress weeds by competing for the use of growth resources and changing environmental factors that affect weed germination and establishment (Liebman and Davis 2000; Saudy and El-Bagoury 2014; Saudy 2015). In the cover crop plots, the greater maize yield may be attributed to improved soil physical properties, nitrogen fixation or recycling, increased soil organic carbon and mineralization, and increased nutrient availability (Isik et al. 2009). The use of cowpea as a living mulch leads to a considerable reduction in weed biomass by about 46% (Jamshidi et al. 2013). Furthermore, straw mulch prevents the seed germination and suppresses the growth of emerging weed seedlings by blocking the light penetration (Chang et al. 2016). In plots treated with straw mulch, weed density was established at 2.8–6.4 times lower compared with weed density in plots without mulch (Sinkevičienė et al. 2009). Moreover, different plant residues are known to have allelopathic properties, which can contribute to weed suppression (Anzalone et al. 2010). Soil mulching significantly improved relative water content and photosynthesis efficiency and reduced weed competition (Abd El-Mageed et al. 2016; El-Metwally et al. 2021). Therefore, maize growth and yield and nutrient uptake were improved because of mulching soil by cowpea or rice straw.

Concerning the exploiting allelopathy phenomenon, the current study showed that sorghum extract caused reasonable suppressive impact on weeds associated maize plants. Reduction in number of weeds and biomass ranged between 35.8–59.5 and 45.8–52.6 in 2018 and 2019 seasons, respectively (Table 3). Allelochemicals can interfere with the basic processes of receiver plants such as photosynthesis, cell division, respiration and protein synthesis (Duke and Dayan 2006) and indirectly stimulate other forms of stress. Also, such allelopathic chemicals activate the cellular antioxidant system in response to uncontrolled production and the accumulation of reactive oxygen species (Bogatek and Gniazdowska 2007). Allelochemicals can inhibit the growth of weeds through photosynthesis inhibition, free radical production, a decline in chlorophyll content, inhibition of enzymatic activity and disruption of the cell membrane and structure of the target plants (Ghanizadeh et al. 2014).

Despite rice straw and hoeing treatments achieved high grain yield, their benefit/cost ratios were lower than other weed control treatment (Table 6). This may be mainly attributed to the high cost of materials and implementation. Relative fewer net return was obtained with foramsulfuron herbicide as a result of low grain yield.

Conclusion

Certainly, the agricultural practice that achieve a package of benefits is regarded as the promising pattern in agricultural production. In this respect, the current study proved that cowpea as a live mulch showed several advantages by intercrop with maize, i.e. suppressing the growth of various weed types, reducing nutrient uptake by weed, increasing yield potential and grain nutrient accumulation as well as high returns. Additionally, cowpea as a legume crop saves additive value expressed in enhancement of soil fertility and produce forage yield. Accordingly, cowpea live mulch as a safe and eco-friendly method to control weeds is recommended in maize cultivation. Despite the high efficiency of rice straw mulch treatment in controlling weeds and producing relatively high maize yield, the high price of straw may pose a stumbling block to its practical use. In fact, the use of natural plant extracts, such as sorghum, in weed control still requires further improvement to convince the farmers to use it a main tool for wed control. However, instead of herbicides, the allelopathic effect of sorghum extract could be incorporated into weed management strategies as an additional, more cost-effective and environmentally friendly method that will help to save the environment.

Conflict of interest H. S. Saudy, M. El-Bially, K. A. Ramadan, E. K. Abo El-Nasr and G. A. Abd El-Samad declare that they have no competing interests.

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