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INTEGRATION OF SOME ALLELOPATHIC SPECIES FOR WEED MANAGEMENT IN SPRING PLANTED HYBRID MAIZE UNDER DIFFERENT TILLAGE REGIMES

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ABSTRACT

A two-year study was conducted on integrated weed management in maize under different tillage regimes at Agricultural Research Station Swabi Khyber Pakhtunkhwa, Pakistan during Spring 2014 and subsequently repeated in 2015. The experiment was laid out at silt loam soil in Randomized complete block design (RCBD) with a split plot arrangement having three replications. Tillage regimes ((minimum, conventional and deep tillage) were kept in main plots (Factor A) and allelopathic plant residues (sorghum, sunflower and parthenium) as surface mulched in various combinations and their water extracts @ 15L each + atrazine @ ¼th of recommended dose were assigned to the sub-plots (Factor B), for weed management in maize. Data during both years (2014 and 2015) were recorded and analyzed for dry biomass of weeds 30 DAS, kernels ear^{-1}, ear length (cm), kernel yield (kg ha^{-1}) and cost benefit ratio. Foliar application of Sorghum + parthenium water extracts at 15 L integrated with a quarter recommended dose of atrazine (pre emergence) under conventional tillage regimes suppressed total weed dry biomass by 34 and 42% at 30 DAS during 2014 and 2015, respectively which increased maize kernel yield by 52 % over the weedy check and was almost equivalent to the label dose of atrazine (0.50 kg a.i ha^{-1}) and also had the highest CBR **(1:20.4).** Among the soil mulch treatments, Sorghum + sunflower +parthenium each at 4 Mg ha^{-1} under deep tillage regimes suppressed weed dry biomass by 69 and 75 % at 30 DAS during 2014 and 2015 respectively, pooled data of both years (2014 and 2015) indicated increase in maize kernel yield by 54 % over control with CBR (1:15:2). However, the mulch treatments and the cost of deep tillage were uneconomical. Hand weeding under deep tillage regimes increased maize kernel yield by 46 % as compared to the weedy check. Based on current studies, it is concluded that foliar application of Sorghum + parthenium aqueous extract integrated with reduced atrazine dose are economical and eco-friendly having the highest CBR. Consequently, reliance on atrazine could be reduced by 75% resulting in environmental safety and sustainability, however further studies are suggested to fine tune our findings.

Key words: Allelopathy, Integrated weed management, tillage, sustainable weed management, maize.

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INTRODUCTION

Maize *(Zea mays* L.) is the third cereal crop after wheat and rice in Pakistan. It is an important spring as well as autumn crop in Pakistan. Maize is known as "Queen of Cereals" due to its higher productivity per unit area and wider adaptability (Kumar *et al*., 2017). In Pakistan, maize is cultivated on an area of 1,413 thousand hectares and has average annual production of 7.24 million tons (Govt. of Pakistan, 2020). Current average maize yield in Pakistan is very low as compared to the world's realized yield (12 tons ha^{-1}). Among other factors responsible for yield reduction in maize, weed infestation is the most important factor reducing maize yield from 24-83 % (Usman *et al*. 2001; Dogan *et al*. 2004; Fahad *et al.* 2014). Weed control is the most important factor for sustainable agriculture (Arif *et al*., 2013). Reduction in crop yield due to weeds is greater than insects and other diseases combined (Ihsan *et al*., 2015; Hassan *et al.,* 2019). The yield of maize could be reduced up to 32% due to horse purslane (*Trianthema portulacastrum)* infestation (Balyan and Bhan, 1989) and up to 80 % due to the competition from rigid ryegrass *(Lolium rigidum)* depending on the season and infestation level (Izquierdo *et al*., 2003). The worst weeds competitive with maize. in Pakistan are purple nutsedge *(Cyprus rotundus* L.*)*, horse purslane (*Trianthema portulacastrum* L.*)*, bermuda grass *(Cynodon dactylon* (L.) Pers., common lambasquarters *(Chenopodium album* L.*)*, barnyard grass *(Echinochloa crus-galli* L. Beauv.*)* and jungle rice *(E. colona* (L.) Link (Muhammad *et al*., 2009). The predominance and competitive ability of weeds with maize or corn varies due to the geographical location, competitive ability of the variety planted, nutrients availability, availability of moisture, soil type and soil management.

The non-judicious use of herbicides can create many environmental and health related problems everywhere in addition to resistance development in weeds (Jabran *et al*., 2018). Environmentalists are deeply concerned with the indiscriminate use of herbicides. Recently 38 weed species have now evolved resistance to glyphosate, in glyphosate resistant crops, spread across 37 countries of the world infesting 34 different crops and six non-crop situations (Heap and Duke, 2018), which includes some worst weeds of the world. Hence, principal reliance on herbicides has become obscure and alternate weed control measures are indispensable. Indiscriminate herbicide usage is driving agro ecosystems towards dwindling species diversity and, in many situations and leading to herbicide resistance (Powels and Yu, 2010; Vila-Aiub *et al*., 2005; Storrie *et al*., 2014). Very recent comprehensive survey of Heap (2020) reveals a gloomy picture of resistant weeds worldwide to the extent of 512 unique cases (species x site of action) of herbicide resistant weeds globally, with 262 species (152 dicots and 110 monocots) have been reported in 93 crops in 70 countries. Hence, the utilization of allelopathic properties of allelopathic plant species offers promising opportunities for sustainable weed management (Lorenzo *et al*., 2013). Allelopathy could thus, be an alternative to the synthetic herbicides because allelochemicals do not have residual effects (Bhadoria, 2011). Several allelopathic plants such as Sorghum (Weston and Duke, 2003), Sunflower (1987; Batish *et al*. 2002) and Parthenium (Adkin and Sowerby ,1996; Hassan *et al*., 2008, Safdar, 2014; Hassan *et al.,* 2018) are inhibitory as well as stimulatory to weeds (at low doses). The application of allelopathy in crop production in Pakistan are successful examples in recent years (Cheema *et al.*, 2013; Khan *et al.,* 2020).

Moreover, it is also observed that allelopathic effect does exist due to a single compound, but ideally interaction of multiple compounds which may work together either in synergistic or additive means (Putnam *et al.* 1983). Although allelochemicals cannot totally suppress weeds but can be mixed with herbicides to use in crops. It is difficult to get the results of allelochemicals which are at par with herbicides efficacy but at least the overall herbicide use can be reduced if the mixture of allelochemicals and herbicide are used (Jabran *et al*., 2018). For environmental integrity Hassan *et al.* (2019) integrated maize cultivars with reduced dose of atrazine and successfully managed weeds and harvested statistically equal yield with the recommended dose of atrazine.

Tillage operations and soil disturbance can usually improve soil aeration and mineralization of organic nitrogen and its availability to plant consumption (Halvorson *et al*., 2001; Dinnes *et al*., 2002). Hence, tillage regimes disturb the composition of weed groups. In maize cropping system soil disturbance is inversely proportional to the number of weed species (Cardina *et al*., 1991). It not only kills weeds, but also disturbs the soil (Mohler and Galford, 1997). Individually the effect of allelopathy and tillage has been well reported (Lorenzo *et al*., 2013; Mohler and Galford, 1997) however the interaction of both has been studied very rarely. Keeping in view the importance of tillage as a fundamental component in the weed management strategies and unlimited opportunities that allelopathy provides and the recognized importance of allelopathins in weed management, the current study was undertaken with the objective to identify an effective and economical allelopathic treatment synergistic with a best tillage regime for weed management in spring planted hybrid maize under field conditions.

MATERIALS AND METHODS

Experimental Site and other details: Field experiment entitled "Integration of allelopathy and reduced dose of atrazine under different tillage regimes for weed management in spring planted hybrid maize**"** was conducted at Agricultural Research Station, Swabi, Khyber Pakhtunkhwa Pakistan during March-June, 2014 and subsequently repeated in the same season during 2015 under the same protocol. Maize hybrid **"**Pioneer 3025**"** was selected as the test crop. Sorghum (*Sorghum bicolor* (L.*)* Moench.*,* sunflower *(Helianthus annuus* L.*)*, and parthenium (*Parthenium hysterophorus* L.*)* residues in equal combination were used for surface mulches (S.M), whereas, their water extracts (WE) combination was mixed with reduced atrazine dosage (¼th of recommended dose (0.50 kg a.i ha^{-1}) for foliar application. Hand weeding and weedy check were also included in the treatments. The experiments were laid out in randomized complete block design (RCBD) with split plot arrangement having three main plots assigned to 3 different tillage regimes, while 12 sub plots were allotted to different weed control measures having a sub-plot size of 3mx2m. Recommended seed rate of maize @25 kg ha^{-1}; row to row distance of 75 cm and plant to plant distance of 15 cm were maintained. The fertilizer was applied @ 150 kg nitrogen + 100 kg phosphorous (P_2O_5) ha^{-1}, as applied in the form of urea and diamonium phosphate (DAP), respectively. The detail of treatments is furnished as under:

Factor (A) Main plots (Tillage systems = 3)
MT = Minimum tillage (rotavator + planking)
CT= Conventional tillage {tine plough (twice) + planking}
DT = Deep tillage (chiesel plough + tine plough + planking)

Factor (B) Sub plots (12 weed control treatments including weedy check)
T1=Sorghum + sunflower (WE) @ 15L each + atrazine @ ¼th of recommended dose of atrazine (Pre emergence).
T2= Sorghum + partheniun (WE) @ 15L each + atrazine @ ¼th of recommended dose of atrazine (Pre emergence).
T3=Sunflower + parthenium (WE) @ 15L each + atrazine @ ¼th of recommended dose of atrazine (Pre-emergence).
T4=Sorghum+ sunflower + parthenium (WE) @ 15L each + atrazine @ ¼th of recommended dose of atrazine (Pre-emergence).
T5= Sorghum + sunflower (SM) each @ 6 Mg ha^{-1} at 3-4 leaf stage of maize.
T6= Sorghum + parthenium (SM) each @ 6 Mg ha^{-1} at 3-4 leaf stage of maize.
T7= Sunflower + parthenium (SM) each @ 6 Mg ha^{-1} at 3-4 leaf stage of maize.
T8= Sorghum+ sunflower + parthenium (S.M) (SM) each @ 4 Mg ha^{-1} at 3-4 leaf stage of maize.
T9=Atrazine @ ¼th of recommended dose sole application (Pre emergence).
T10=Atrazine @ 0.50 kg a.i ha^{-1} or recommended rate (Pre emergence).
T11=Hand weeding 30 days after germination of maize (once)
T12=Weedy check

Collection of Allelopathic Plants: Fresh plants of Sorghum, sunflower and parthenium were collected from farmers' field in district Swabi. All plant samples were washed to remove dust and other particles and were chopped by electric cutter into 3-4 pieces and dried in oven (Kenton; KH-120AS) for 72 hours at 65°C and were ground with the help of electrical grinder.

Preparation of Extracts: Oven dried powder of allelopathic plants were soaked in water 1:10 (w/v) for 48 hours. Finally, extracts were filtered through muslin cloth to obtain respective water extracts (Cheema and Khaliq, 2000). Quarter dose (¼ of recommended dose of atrazine) was tank mixed with each extract.

Preparation of Surface Mulches: Surface mulches were prepared by obtaining the whole plants of sorghum. sunflower and parthenium by harvesting at maturity, dried, chaffed with electric cutter into 3-4 cm pieces and stored under cover to avoid possible leaching by rainwater. The chaffed mulches were integrated in different combinations according to treatments and applied as surface application in respective plots 15-20 days after crop emergence during both the years.

Data Recording and Parameter studied

Dry biomass (g) plant $^{-1}$: Fresh biomass of all plant species was dried in an oven for 48 hours at 65^0 C and dry biomass (g) was obtained.

Cob length (cm): Ten cobs from each subplot were randomly collected, measured and means were calculated.

Number of kernels cob^{-1}: Ten cobs from each subplot were randomly collected, and kernels of each cob was calculated and averaged.

Kernel yield (kg ha^{-1}): After harvesting the economic yield i.e., kernel yield was recorded by weighting the kernels in kg for each subplot and subsequently converted to kg ha^{-1}.

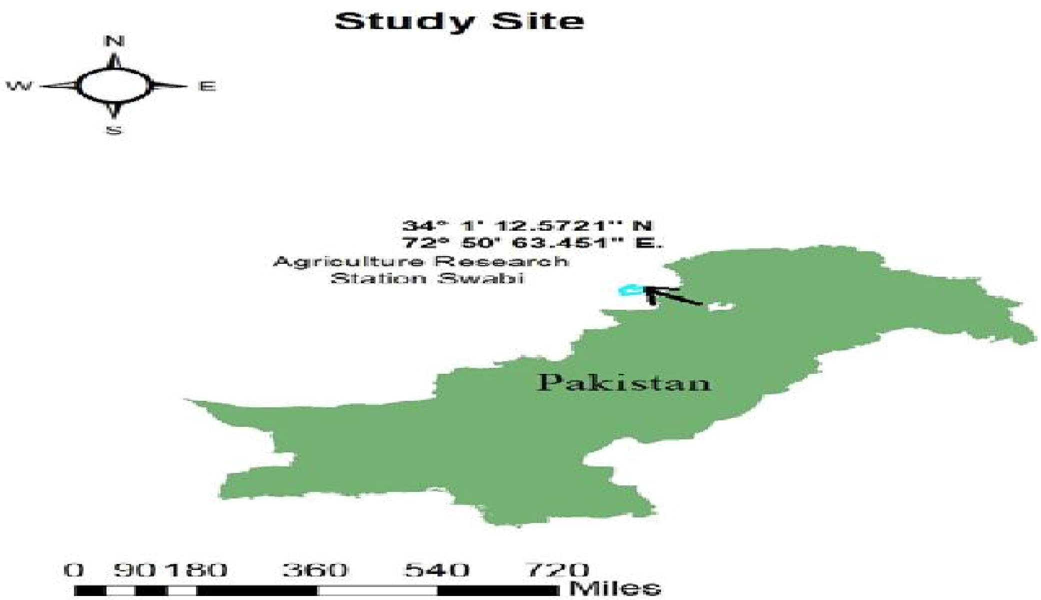
Economic Analysis and Cost benefit ratio: The cost benefit ratio was calculated by dividing added income on Added cost in PKR.

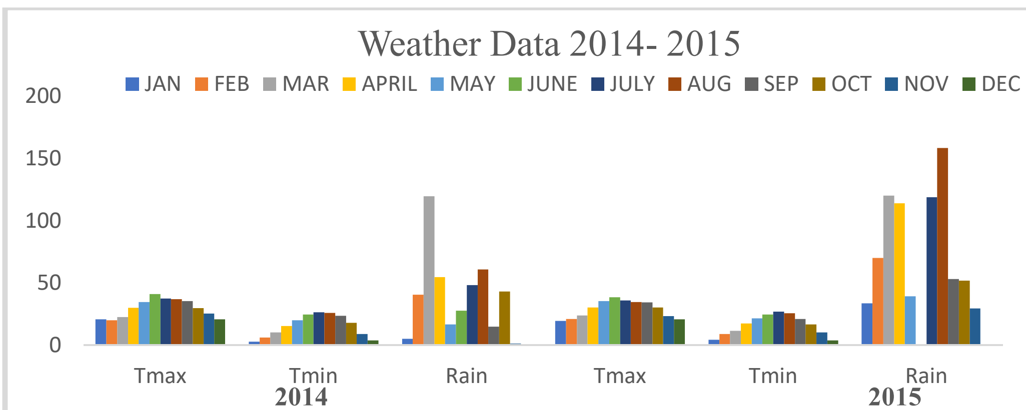
Statistical analyses: The data recorded were analyzed statistically year wise as well as combined over years using analysis of variance techniques suitable for Randomized Complete Block Design with split plot arrangement. Means were separated using Least Significant Difference test at 0.05 probability level, when the F values were significant (Steel *et al.,* 1997). The statistical software Statistix 8.1 was used for the analysis of data.

Soil Physicochemical analysis: The composite soil sample was collected at surface (0-30 cm) depth from the experimental site at Agriculture Research station (ARS), Swabi Khyber Pakhtunkhwa, Pakistan. Analysis was carried out by the methodology as described by Page *et al*. (1982) and Motsara and Roy (2008).

Table 1. 1. Soil physicochemical properties of experimental site (0-30 cm depth).

Soil parameters	**Tillage depths (0-30 cm)**
Textural class	Silt Loam
Clay (%)	15.13
Silt (%)	60.67
Sand (%)	21.8
Ph	7.63
EC (d Sm^{-1})	0.06
Organic matter (%)	0.71
Total N (%)	0.028
Available P (mg kg^{-1} soil)	4.17
Extractable K (mg kg^{-1} soil)	105





RESULTS

Dry biomass (g) plant^{-1}of weeds 30 DAS: Dry biomass (g) of weeds 30 DAS was significantly influenced by different tillage regimes, application of various weed control treatments and their interaction tillage regimes x weed control treatments ($P \leq 0.05$). Whereas, years as a source of variation was also significantly influenced the weed biomass (Table 1.2). Dry biomass (g) of total weeds 30 DAS (55.043) recorded was higher during 2014 as compared to 35.53 g as recorded in 2015. For the main plots, the minimum biomass plant^{-1}was recorded as 48, 32 and 40 in 2014, 2015 and mean of the two years, respectively under deep tillage, while the highest biomass of weeds was observed under minimum tillage (Table 1.2). For the sub-plots significantly lowest biomass of weeds (32 g) was recorded in sorghum + sunflower (SM) each @ 6 Mg ha^{-1} during 2014, while in 2015 and the 2-years mean the lowest dry weight of weeds was recorded in sunflower +sorghum + parthenium (SM) each @ 4 Mg ha^{-1} weighing only 16 and 23 g, respectively. The data in Table 1.2 further showed that the highest biomass of weeds was deciphered in Atrazine @ ¼th of recommended dose sole application, attaining the weight of 105, 71 and 88 g in 2014, 2015 and 2 years mean, respectively. It was even higher than the weedy check. Among the interactions (tillage x weed control treatments) on the 2 years. mean data exhibited minimum dry biomass (14.83) as recorded in sunflower + parthenium (SM) each @ 6 Mg ha^{-1} treatment under minimum tillage regime. In the least dry weight, it was followed by the Recommended dose of atrazine (19.15 g) under minimum tillage (Fig. 1). While, among the different tillage regimes, maximum dry biomass of weeds 30 DAS (123.52 g) was recorded in the Atrazine @ ¼th of recommended dose sole application x minimum tillage followed by the weedy check x conventional tillage (88.28 g) (Fig. 1). Pooled data of two years (2014 and 2015) indicated that dry biomass (g) of weeds 30 DAS ranged from (22.89 an d87.64g) for weed control treatments. Maximum dry biomass (87.64) was recorded in Atrazine @ ¼th of recommended dose sole application followed by control (weedy check) treatment with (80.58 g), whereas minimum dry biomass (22.89 g) was observed in sunflower +sorghum + parthenium (SM) each @ 4 Mg ha^{-1} (Table 1.2)

Ear Length (cm): Data regarding ear length (cm) is presented in Table 1.3. Analysis of variance exhibited that Years, tillage regimes, allelopathic treatments and tillage x allelopathic treatments were significant statistically. As far as the Ear Length of maize is concerned. for the Factor A viz., tillage regimes, the longest ears or cobs (15.72 cm) were recorded in the conventional tillage, but it was statistically at par with the deep tillage (15.42 cm) during the study year 2014 (Table 1.3). Similar trend in the data for tillage regimes were recorded during the subsequent year of study, but the differences were non-significant statistically (P>0.05). However, the data pooled over the years was highly significant statistically (P≤0.01). The longest cobs (15.931 cm) were recorded in the deep tillage which however were statistically at par with the minimum tillage (15.722 cm), which it turns was statistically comparable with the minimum tillage (15.167 cm) (Table 1.3). For the allelopathic treatments during 2014, the longest ears/cobs (16.33 cm ea.) were measured in sorghum + parthenium (SM) each @ 6 Mg ha^{-1}and sunflower + parthenium (SM) each @ 6 Mg ha^{-1}which were however, statistically at par with few other treatments including Atrazine @ 0.50 kg a.i ha^{-1}, while the smallest cobs (12 cm) were recorded in the weedy check and Atrazine @ ¼th of recommended dose sole application (Table 1.3). A similar trend was recorded during 2015 and the pooled data over the years.

No. of kernels ear^{-1}: No. of kernels ear^{-1} is an important yield component. The differences were significantly influenced by different tillage regimes and application of various weed control treatments (P≤0.01) (Table 1.4). Likewise, interaction between tillage regimes x weed control measures had also significant effect on kernels ear^{-1} of maize (P≤0.01). Year as a source of variation had also significant effect on the trait under study (P≤0.05). For the main plots i.e. tillage regimes (Table 1.4), the highest No. of kernels ear^{-1} were recorded in the deep tillage viz., 453, 458 and 455 during 2014, 2015 and pooled over the two years data, respectively. For the allelopathic treatments, the highest kernels were recorded as 494, 525 and 519 during 2014, 2015 and the pooled data over two years, respectively in sorghum + sunflower+ parthenium (S.M) each @ 4 Mg ha^{-1}, which however, was statistically at par with sunflower + parthenium (SM) each @ 6 Mg ha^{-1} producing 472, 507 and 489 kernels ear^{-1} during 2014, 2015 and pooled over the two years, respectively (Table 1.4). Among the interactions (tillage x weed control treatments), the perusal of data in Fig. 1.3 exhibited maximum kernels ear^{-1} (556.3) recorded in sorghum + sunflower+ parthenium (S.M) each @ 4 Mg ha^{-1} under the deep tillage, which was closely followed by the same allelopathic treatment involving conventional (527.8), which further in turn was closely followed by sunflower + parthenium (S.M) each @ 6 Mg ha^{-1} x deep tillage (525.5) (Fig. 1.3). However, the lowest No. of grain ear^{1} were counted in the weedy check involving minimum (320), conventional (339.17 and deep tillage (360.5), respectively (Fig. 1.3). Pooled data of two years revealed that kernels ear^{-1} ranged from 339.89 to 509.50, as affected by various weed control treatments.

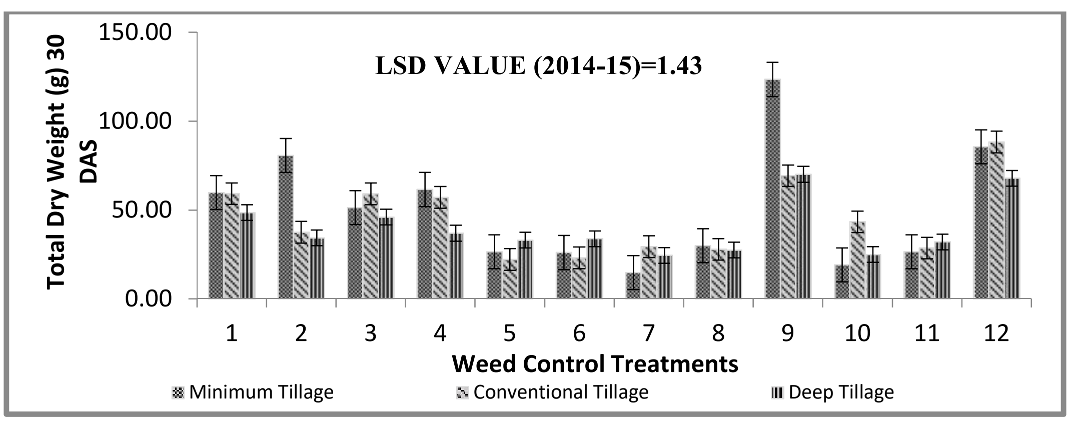
Kernel yield (kg ha^{-1}): Analysis of the data indicated that kernel yield (kg ha^{-1}) was significantly influenced by different tillage regimes, weed management tactics and their interaction. Year as a source of variation had also significant effect on kernel yield (kg ha^{-1}). For the years, kernel yield (5774 kg ha^{-1}) was recorded during 2015 of the study was statistically higher than 5397 kg ha^{-1} as harvested in the preceding year. For the main plots, tillage treatments, during the either year of study the highest kernel yield 6232 and 6477 kg ha^{-1} during 2014 and 2015 was harvested in the deep tillage, which was statistically followed by the conventional tillage producing 5240 and 5689 kg ha^{-1} during successive years of study. Minimum tillage remained the poorest performer in the categories of tillage (Table 1.5). For the sub-plots, among the weed control treatments, the treatment sorghum + sunflower + parthenium (S.M) each @ 4 Mg ha^{-1} out-yielded the rest of the treatments under the 2 years mean data (Fig. 1.4). It amounted to 6362, 6442 and 6502 kg ha^{-1}during 2014, 2015 and 2- years mean data, respectively (Table 1.5). In 2014, the top ranking treatment was also at par with sorghum + parthenium (S.M) each @ 6 Mg ha^{-1} producing 6030 kg ha^{-1}, sorghum + sunflower (S.M) each @ 6 Mg ha^{-1} yielding 6019 kg ha^{-1} and sorghum + sunflower (WE) @ 15L each + atrazine @ ¼th of recommended dose of atrazine yielding 5872 kg ha^{-1}. The minimum yield (3024 kg ha^{-1}) was harvested from the Atrazine @ ¼th of recommended dose sole application and the weedy check (2931 kg ha^{-1} (Table 1.5). During the succeeding year i.e 2015, the highest kernel yield was again harvested from sorghum+ sunflower + parthenium (SM) each @ 4 Mg ha^{-1}, thus validating the findings of 2014. Highest yielding treatment was statistically at par with sorghum + sunflower (S.M) each @ 6 Mg ha^{-1}, while the lowest yield was realized in the weedy check (2981 kg ha^{-1}) like the previous year of study. Atrazine @ 0.50 kg a.i ha^{-1} could yield 5835 kg and 5974 kg ha^{-1} during 2014 and 2015, respectively being statistically lower than the top-ranking treatments. The 2 year mean data also validates these trends (Table 1.5). Among the interaction (tillage x weed control treatments) on the 2 years mean data, maximum grain yield 7611, 7401 and 7315 kg ha^{-1}) were recorded in sorghum + parthenium (S.M) each @ 6 Mg ha^{-1}, Atrazine @ 0.50 kg a.i ha^{-1}, sunflower + parthenium (S.M) each @ 6 Mg ha^{-1} and sorghum + sunflower +parthenium (S.M) each @ 4 Mg ha^{-1}, all involving deep tillage regime (Fig. 1.4). The poorest interactions of tillage x weed management treatments involved the minimum tillage, while the conventional tillage interacted with the weed management treatments as intermediate as far the kernel yield is concerned (Fig. 1.4).

COST BENEFIT RATIO: The cost benefit ratio (CBR) showed that all allelopathic plant water extracts @ 15L each + atrazine @ ¼th of its recommended dose were economical as compared to surface mulches, atrazine full dose, hand weeding and weedy check treatments. Sorghum + parthenium (WE) @ 15L each + atrazine @ ¼th of recommended dose of atrazine under conventional tillage regime provided the highest net return with cost benefit ratio of **1:20.4** (Table 1.6). Furthermore, sorghum + sunflower +parthenium (WE) @ 15L each + atrazine @ ¼th of recommended dose of atrazine x minimum tillage showed **1:19.5** cost benefit ratio. Although the grain yield in surface mulch treatments were higher, but due to higher cost and maintenance concerns it was found uneconomical (Table 1.9).

Table 1.2 Dry biomass (m^{-2}) 30 DAS in spring planted maize as affected by integration of various allelopathic extracts and mulch treatments under different tillage regimes.

Tillage regimes	Tillage codes	2014 *	2015 *	Pooled **
Minimum tillage	MT	62 a*	39 b	**50 A**
Conventional tillage	CT	55 b	36 c	**45 B**
Deep tillage	DT	48 c	32 a	**40 C**
	$LSD_{0.05}$	0.98	0.41	0.94
Sub-PlotTreatments				
Sor + SF + ¼th recomm. atrazine (WE)	T1	66 d	46 c	**56 C**
Sor + Par +¼th recomm. atrazine (WE)	T2	63 ef	38 e	**51 E**
SF + Par +¼th recomm. atrazine (WE)	T3	67 d	38 e	**52 D**
Sor + SF+ Par+¼th recomm. atrazine (WE)	T4	62 f	41 d	**52 D**
Sor + SF (S.M)	T5	32 l	22 f	**27 H**
Sor + Par (S.M)	T6	36 jk	20 g	**28 GH**
SF + Par (S.M)	T7	34 kl	23 f	**28 GH**
Sor + SF+ Par (S.M)	T8	30 m	16 h	**23 I**
Atrazine @ ¼th recomm. Alone	T9	105 a	71 a	**88 A**
Atrazine recomm. rate @ 0.50 kg a.i ha^{-1}	T10	35 k	23 f	**29 F**
Hand weeding	T11	35 k	23 f	**29 F**
Weedy check	T12	96 b	65 b	**81 B**
	$LSD_{0.05}$	1.21	1.88	**0.82**
Means	Years	55.04 **A**	35.54 **B**	**45.29**
Interaction (Tillage x treatments)	Til x T	0.00	0.00	**0.00**

*For each effect, values with same letter(s) in a column do not differ significantly at p≤0.05 according to $LSD_{0.05}$



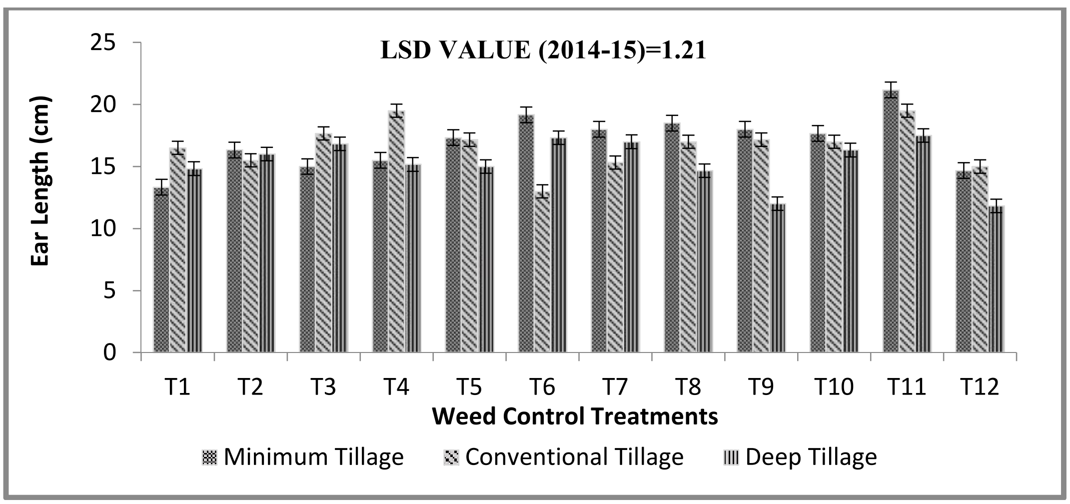
Vertical bars show standard error of mean of three replicates.

Fig 1.1. Interaction between Tillage x allelopathic treatments on dry biomass (g) of total weeds 30 DAS in spring planted maize during 2014 and 2015 Ear Length (cm).

Table 1.3 Ear Length (cm) in spring planted maize as affected by integration of various allelopathic extracts and mulch treatments under different tillage regimes.

Main Plots Tillage regimes	Tillage codes	2014*	2015**	Pooled***
Minimum tillage	MT	14.75 b	15.58	15.167 B
Conventional tillage	CT	15.72 a	15.72	15.722 AB
Deep tillage	DT	15.42 ab	16.44	15.931 A
	$LSD_{0.05}$	0.73	NS	0.624
Sub-Plot Treatments				
Sor + SF + ¼th recomm. atrazine (WE)	T1	14.78 cd	15.00 d	14.89 DE
Sor + Par +¼th recomm. atrazine (WE)	T2	15.11 bc	15.67 cd	15.39 CD
SF + Par +¼th recomm. atrazine (WE)	T3	15.78 a-c	16.44 ac	16.11 A-C
Sor + SF+ Par+¼th recomm. atrazine (WE)	T4	16.00 ab	16.11 bc	16.06 A-C
Sor + SF (S.M)	T5	16.22 ab	15.89 b-d	16.06 A-C
Sor + Par (S.M)	T6	16.33 a	16.33 a-c	16.33 AB
SF + Par (S.M)	T7	16.33 a	17.22 a	16.78 A
Sor + SF+ Par (S.M)	T8	16.22 ab	16.78 ab	16.50 AB
Atrazine @ ¼th recomm. Alone	T9	13.78 d	15.00 d	14.39 E
Atrazine recomm. rate @ 0.50 kg a.i ha^{-1}	T10	15.89 a-c	17.33 a	16.61 A
Hand weeding	T11	15.11 bc	16.33 ac	15.72 BC
Weedy check	T12	12.00 e	12.89 e	12.44 F
	$LSD_{0.05}$	1.21	1.051	0.794
Means	Years	15.94 **a**	16.82 a	
Interaction (Tillage x Treatments)	Til x T	0.00	0.00	0.00

*For each effect, values with same letter(s) in a column do not differ significantly from one another at $p \leq 0.05$ according to LSD test.



Vertical bars show standard error of mean of three replicates.

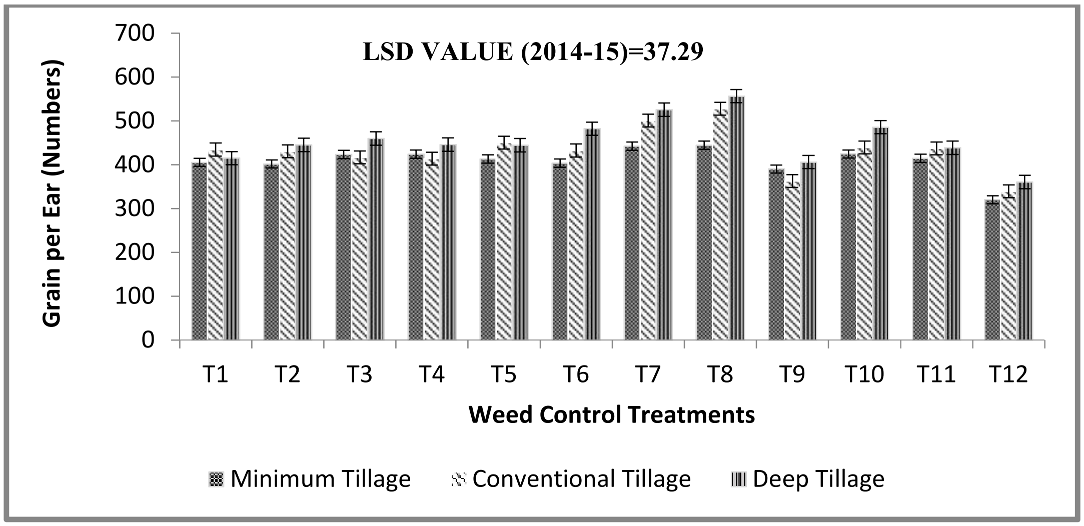
Fig. 1.2 Interaction between Tillage x allelopathic treatments on Ear length in maize on two-year mean.

Table 1.4. No. of kernels Ear^{-1} in spring planted maize as affected by integration of various allelopathic extracts and mulch treatments under different tillage regimes.

Tillage regimes	Tillage codes	2014*	2015**	Pooled***
Minimum tillage	MT	387 c*	430	409 C
Conventional tillage	CT	418 b	446	432 B
Deep tillage	DT	453 a	458	455 A
	$LSD_{0.05}$	25.28	NS	16.71
Sub-Plot Treatments	Treatments			
Sor + SF + ¼th recomm. atrazine (WE)	T1	403 e	434 bc	418 C
Sor + Par +¼th recomm. atrazine (WE)	T2	414 de	438 b	426 C

SF + Par +¼th recomm. atrazine (WE)	T3	408 de	458 b	433 BC
Sor + SF+ Par+¼th recomm. atrazine (WE)	T4	415 de	440 b	428 C
Sor + SF (S.M)	T5	436 cd	436 bc	436 BC
Sor + Par (S.M)	T6	422 ce	457 b	439 BC
SF + Par (S.M)	T7	472 ab	507 a	489 A
Sor + SF+ Par (S.M)	T8	494 a	525 a	510 A
Atrazine @ ¼th recomm. Alone	T9	368 f	404 c	386 D
Atrazine recomm. rate @ 0.50 kg a.i ha^{-1}	T10	447 bc	453 b	450 B
Hand weeding	T11	416 de	444 b	430 BC
Weedy check	T12	337 g	343 d	340 E
	$LSD_{0.05}$	29.3	32.58	21.53
Means	Years	419 **B**	445 **A**	
Interaction (Tillage x Treatments)	Tx H	0.32	0.00	0.00

*For each effect, values with same letter(s) in a column do not differ from one another at p ≤0.05 according to $LSD_{0.05}$ test.



Vertical bars show standard error of mean of three replicates.

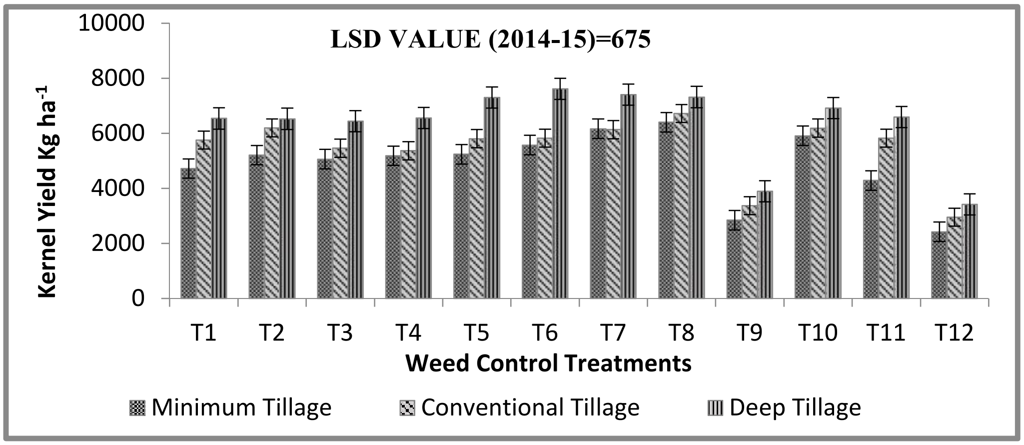
Fig. 1.3. Interaction between Tillage and various allelopathic treatments on kernels Ear^{-1} in spring planted maize during 2014 and 2015.

Table 1.5 Kernel yield (kg ha^{-1}) in spring planted maize as affected by integration of various allelopathic extracts and mulch treatments under different tillage regimes.

Main Plots Tillage regimes	Tillage codes	2014*	2015**	Pooled***
Minimum tillage	MT	4218 ^{c}	4239 ^{c}	4229 ^{C}
Conventional tillage	CT	5240 ^{b}	5689 ^{b}	5465 ^{B}
Deep tillage	DT	6232 ^{a}	6477 ^{a}	6355 ^{A}
	$LSD_{0.05}$	305.39	286.98	174.02
Sub Plots	Treatments			
Sor + SF + ¼th recomm. atrazine (WE)	T1	5872 $^{a-c}$	5112 ^{d}	5492 ^{C}
Sor + Par +¼th recomm. atrazine (WE)	T2	5508 $^{c-e}$	5998 ^{bc}	5753 ^{BC}
SF + Par +¼th recomm. atrazine (WE)	T3	5223 ^{e}	5519 ^{bc}	5521 ^{C}
Sor + SF+ Par+¼th recomm. atrazine (WE)	T4	5329 ^{de}	5628 ^{c}	5478 ^{C}
Sor + SF (S.M)	T5	6019 $^{a-c}$	5552 ^{cd}	5786 ^{BC}
Sor + Par (S.M)	T6	5541 $^{b-e}$	6256 ^{ab}	5899 ^{B}
SF + Par (S.M)	T7	6030 ^{ab}	6123 ^{b}	6077 ^{B}
Sor + SF+ Par (S.M)	T8	6362 ^{a}	6642 ^{a}	6502 ^{A}
Atrazine @ ¼th recomm. Alone	T9	3024 ^{f}	3714 ^{e}	3369 ^{D}
Atrazine recomm. rate @ 0.50 kg a.i ha^{-1}	T10	5835 $^{b-d}$	5974 ^{bc}	5905 ^{B}
Hand weeding	T11	5084 ^{e}	5822 ^{bc}	5453 ^{C}

Weedy check	T12	2931 f	2981 f	2956 E
	$LSD_{0.05}$	517.00	489.56	352.71
Means	Years	5230.3 B	5468.4 A	
Interaction (Tillage x Treatments)	Til x T	0.04	0.05	0.00

*For each effect, values with same letter(s) in a column do not differ from one another at p ≤0.05 according to $LSD_{0.05}$ test.



Vertical bars show standard error of mean of three replicates.

Fig 1.4. Interaction between Tillage and various allelopathic treatments on kernel yield (kg ha^{-1}) in spring planted maize during 2014 and 2015.

Table 1.6 Economic Analysis (Minimum tillage).

Weed Control Treatments	Grain Yield/ha	Yield Increased Over Control/ha	Value of increased yield/ha	Additional Expenditure/ha	Net income	Cost Benefit Ratio (CBR)
Sor + SF + 1/4 Atrazine (WE)	4353.8	1818	36360	2040	34320	16.82
Sor + Par + 1/4 Atrazine (WE)	4539.8	2004	40080	2080	38000	18.27
SF + Par + 1/4 Atrazine (WE)	4665.8	2130	42600	2175	40425	18.59
Sor + SF+ Par+ 1/4 Atrazine (WE)	4515.3	1979.5	39590	1930	37660	19.51
Sor + SF (S.M)	4402.8	1867	37340	7900	29440	3.73
Sor + Par (S.M)	4572	2036.2	40724	5600	35124	6.27
SF + Par (S.M)	4819.5	2283.7	45674	6100	39574	6.49
Sor + SF+ Par (S.M)	4937.8	2402	48040	6440	41600	6.46
1/4 dose of Atrazine	2843.2	307.4	6148	1237	4911	3.97
Full dose of Atrazine	4613	2077.2	41544	2550	38994	15.29
Hand Weeding	3946.2	1410.4	28208	2700	25508	9.45
Control	2535.8	*	*	*		*

Table 1.7. Economic Analysis (Conventional tillage).

Weed Control Treatments	Grain Yield/ha	Yield Increased Over Control/ha	Value of increased yield/ha	Additional Expenditure/ha	Net income	Cost Benefit Ratio (CBR)
Sor + SF + 1/4 Atrazine (WE)	5750.5	2801.2	56024	2990	53034	17.74
Sor + Par + 1/4 Atrazine (WE)	6194.3	3245	64900	3030	61870	20.42
SF + Par + 1/4 Atrazine (WE)	5457.2	2507.9	50158	3125	47033	15.05
Sor + SF+ Par+ 1/4 Atrazine (WE)	5364.7	2415.4	48308	2880	45428	15.77
Sor + SF (S.M)	5805.5	2856.2	57124	8850	48274	5.45
Sor + Par (S.M)	5820.2	2870.9	57418	8300	49118	5.92
SF + Par (S.M)	6131.3	3182	63640	7050	56590	8.03

Sor + SF+ Par (S.M)	6719	3769.7	75394	7390	68004	9.2
1/4 dose of Atrazine	3372.3	423	8460	2187	6273	2.87
Full dose of Atrazine	6188	3238.7	64774	3500	61274	17.51
Hand Weeding	5823.5	2874.2	57484	3650	53834	14.75
Control	2949.3	*	*	*		*

Table 1.8. Economic Analysis (Deep tillage).

Weed Control Treatments	Grain Yield/ha	Yield Increased Over Control/ha	Value of increased yield/ha	Additional Expenditure /ha	Net income	Cost Benefit Ratio (CBR)
Sor + SF + 1/4 Atrazine (WE)	6371.5	2988.3	59766	4040	55726	13.79
Sor + Par + 1/4 Atrazine (WE)	6525.7	3142.5	62850	4080	58770	14.4
SF + Par + 1/4 Atrazine (WE)	6440.8	3057.6	61152	4175	56977	13.65
Sor + SF+ Par+ 1/4 Atrazine (WE)	6556.5	3173.3	63466	3930	59536	**15.15**
Sor + SF (S.M)	7148.7	3765.5	75310	9900	65410	6.61
Sor + Par (S.M)	7304.7	3921.5	78430	9350	69080	7.39
SF + Par (S.M)	7279.3	3896.1	77922	8100	69822	8.62
Sor + SF+ Par (S.M)	7849.7	4466.5	89330	8440	80890	9.58
1/4 dose of Atrazine	3892.7	509.5	10190	3237	6953	2.15
Full dose of Atrazine	6912.7	3529.5	70590	4550	66040	14.51
Hand Weeding	6590.3	3207.1	64142	4700	59442	12.65
Control	3383.2	*	*	*		*

Table 1.9. Combined (2 yr. mean) Cost benefit ratio (CBR).

Weed Control Treatments	WC treatment	Minimum Tillage	Conventional Tillage	Deep Tillage
Sor + SF + ¼ recommended atrazine (WE)	T1	1:16.8	1:17.7	1:13.8
Sor + Par + ¼recommended atrazine (WE)	T2	1:18.3	**1:20.4**	1:14.4
SF + Par + ¼ recommended atrazine (WE)	T3	1:18.6	1:15.1	1:13.7
Sor+SF+ Par+¼ recommended atrazine (WE)	**T4**	**1:19.5**	1:15.8	**1:15.2**
Sor + SF (S.M)	T5	1:3.7	1:5.5	1:6.6
Sor + Par (S.M)	T6	1:6.3	1:5.9	1:7.4
SF + Par (S.M)	T7	1:6.5	1:8.0	1:8.6
Sor + SF+ Par (S.M)	T8	1:6.5	1:9.2	1:9.6
¼ recommended atrazine alone	T9	1:3.1	1:2.9	1:2.2
Recommended dose of atrazine	T10	1:15.3	1:17.5	1:14.5
Hand Weeding	T11	1:9.5	1:14.8	1:12.7
Weedy check	T12	*	*	*

DISCUSSION

Our results obtained for different tillage regimes are in conformity with the findings of Cardina *et al.* (1991) and Mohler and Galford (1997), who reported that in minimum tillage weed density of various species could be increased. These results are also in agreement with the findings of Khattak *et al.* (2005), who stated that with the increasing frequency of tillage, density of weed species was reduced due to the destruction of annual and perennial germinated weeds in the soil, which ultimately reduced the total fresh and dry biomass of weed species. In weed control treatments the highest biomass of weeds was deciphered in Atrazine @ ¼th of recommended dose sole application probably due to hormesis effect (stimulation of growth in plants due to xenbiotics applied at sub-lethal doses). The definition of hormesis derived by Stebbing (1982) is low-dose stimulation followed by higher-dose inhibition; the most common form of hormesis follows the widely recognized ß-curve. Whereas the significant effect of surface mulches against dry biomass 30 DAS of total weed species could be partially attributed due to the reported allelochemicals. Sorgoleone in *Sorghum bicolor* responsible for inhibiting the electron transport in both photosynthesis and respiration (Nimbal *et al.*,1996) and other compounds like vanillic and ferulic acids reported in parthenium, sorghum and sunflower plants are responsible for DNA and RNA synthesis (Baziramakenga *et al.,* 1997). Higher inhibition of mulch treatment than herbicide (label dose) could further be exploited for sustainable management of weeds however, the cost and economics of mulches must be kept under consideration.

Maximum length of ear in deep tillage followed by conventional tillage could be due to reduction of soil bulk density and improved soil aeration which can allow the crop to utilize the available nutrients from the root zone during the shoot development stage. Our results are in confirmatory to the previous findings of Aikins and Afuakwa (2010) who deduced that plant shoot development is reliant on development of root, while plant vegetative growth increased when soil depth is increased which could explore more nutrients and moisture. It is depicted from these data that the leading allelopathic treatments are a good substitute of atrazine at recommended dose, as the leading herbicide in maize for the environmental integrity, workers safety and economy. Enormous literature around the world has ascertained the worth of plant allelopathy for management of weeds (Adkins and Sowerby, 1996; Nimbal *et al.,* 1996; Khan *et al.* (2012), Hassan *et al*., 2018 and Jabran *et al.,* 2018). Since allelopathins successfully managed weeds thereby deep tillage proved ineffective to express its worth in weed management and culminate in improved ear or cob size (Fig. 1.2).

Number of grain ear^{-1} is an important factor for grain yield. If the number of grains in an ear, yield will be higher. Analysis of both years showed that maximum number of cob ear^{-1} in 2nd year (2015) could be attributed to more rain fall than in 1st year (Table 1.1) . Our results for different tillage regimes are in agreement with Albuquerque *et al* (2001) who reported that grains ear^{-1} were reduced in zero tilled compared to the tilled plots. Similar results were reported by Khan *et al.* (2009), who reported that tillage has significant effect on the number of grains per cob.

Kernel yield is the ultimate sacred goal of the famers. Kernel yield is dependent on its components viz., No. of plants per unit area, No. of cobs per plant, No. of grain per cob, 1000 kernel weight and ratio of photo-assimilate partitioned towards the economic yield. All these parameters interact among each other and as a consequence net grain yield is harvested by a farmer. These findings are in contrast with the recent findings of Khan *et al*. (2020) who deciphered that hand weeding and herbicides significantly increased kernel weight (g), kernel number ear^{-1}, and grain yield (kg ha^{-1}) is in contrast to our findings as our allelopathic treatments surpassed the yield harvested in hand weeding and atrazine application. However, earlier studies of Batish *et al.* (2002) concluded that sunflower residues minimized the weed density and significantly increased the yield of three summer crops including maize. Studies of Khan *et al.* (2012) on weed management through allelopathic plant water extracts showed 70-75% suppression of weeds density and dry weight when used in combination with half and 1/3rd dose of atrazine are in agreement with the present findings to mitigate the pollution and other hazards of herbicides through synergistic action of reduced dose of atrazine and aqueous extracts of allelopathic crops in combination.

Cost benefit ratio (CBR) of all water extracts applied @ 15L each + atrazine @ ¼th of recommended dose were economical when compared to mulches, Atrazine @ 0.50 kg a.i ha^{-1}, Atrazine @ ¼th of recommended dose sole application, and hand weeding. Sorghum + parthenium (WE) @ 15L each + atrazine @ ¼th of recommended dose of atrazine under conventional tillage regime provided the highest net return with cost benefit ratio of 1:20.4 (Table 1.6). Although the grain yield in surface mulch treatments were higher, but due to higher cost and maintenance concerns it was found uneconomical (Table 1.9). These findings are supported by the recent findings of Khan *et al*. (2020) who showed that among the plant extracts, *Euclyptus camaldulensis* was the promising in suppressing weeds in open pollinated maize crop, while Khan *et al.* (2009) who have shown the worth of sunflower extracts as weed killers.

Conclusions: Foliar application of sorghum + parthenium (WE) @ 15L each + atrazine @ ¼th of recommended dose of atrazine (pre-emergence) under conventional tillage regimes suppressed total weed dry biomass by 34 and 42 % at 30 DAS during 2014 and 2015, respectively which increased maize grain yield by 52 % over control and was almost equivalent to the label dose of atrazine (0.50 kg a.i ha^{-1}) and also had highest CBR (1:20.4). Among the mulch treatments, sorghum + sunflower + parthenium (SM) each at 4 Mg ha^{-1} under deep tillage regimes suppressed weed dry biomass by 69-75 % at 30 DAS during 2014 and 2015, respectively and increased maize grain yield by 54 % over control with CBR (1:15.2). All mulch treatments and the cost of deep tillage were uneconomical.

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