INTRODUCTION
Maize (Zea mays L.) is the third most economically important cereal crop after rice and wheat in India and is being used as food, feed and in the preparation of vast industrial products like starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, textiles, package and paper industries. Weed infestation is the major biotic stress responsible for the lower yield of maize in India (Rao et al. 2014, Rao and Chauhan 2015). Grain losses in maize varied between 28-100%, if weeds were not controlled during the critical stages of crop weed competition (Kumar et al. 2017) by competing for water, light, nutrients, space and other resources. Weeds also interfere with the harvesting process and ultimately increase the production cost. The critical period for weed control starts from four to six-leaf stage and may continue until ten leaf stage or flowering of maize (Gantoli et al. 2013). Hand weeding is most popular among the farmers for weed control but it is expensive, laborious and time-consuming. In India an acute shortage of labour occurs where the peak labour requirement is often for hand weeding. The application of herbicides for weed control is an important alternative to manual weeding because they are cheaper, faster and give better weed control. Usage of pre-emergence herbicides assumes greater importance in view of their effectiveness during initial stages. As the weeds interfere during aftercare operation and the harvesting of the crop, post-emergence or sequential use of herbicides may help in avoiding the problem of weeds at later stages. Some herbicides with residual effects may restrict the emergence and growth of succeeding crops in rotation. Hence, the present investigation was carried out to study the effect of sequential application of pre- and post-emergence herbicides on weeds and maize growth and yield and their residual effect in succeeding greengram cropping system.

MATERIALS AND METHODS
An experiment was conducted during the two consecutive years of winter, 2017-18, 2018-19 and summer, 2018 and 2019 at wetland farm of S.V. Agricultural College, Tirupati, Andhra Pradesh, in a randomized block design with ten weed management treatments and three replications. The lowest weed density and biomass, highest weed control efficiency and maize growth parameters, yield attributes, kernel and straw yields were recorded with hand weeding (HW) twice at 15 and 30 days after seeding (DAS), which was statistically at par with atrazine 1.0 kg/ha as pre-emergence application (PE) followed by (fb) topramezone 30 g/ha or tembotrione 120 g/ha as post-emergence application (PoE) or one HW at 30 DAS. Higher greengram seed yield, haulm yield, and lower total weed density and biomass in succeeding greengram were noticed with HW twice at 15 and 30 DAS, which was comparable with atrazine 1.0 kg/ha as PE fb one HW at 30 DAS or topramezone 30 g/ha or tembotrione 120 g/ha or halosulfuron methyl 67.5 g/ha as PoE applied in maize. Based on this study it was concluded that atrazine 1.0 kg/ha as PE fb topramezone 30 g/ha or tembotrione 120 g/ha can be used for the most effective weed management to increase the productivity in winter maize followed by summer greengram cropping system.
longitude, at an altitude of 182.9 m above the mean sea level in the Southern Agro-Climatic Zone of Andhra Pradesh, India. The soil of the experimental site was sandy clay loam in texture, neutral in soil reaction, low in organic carbon (0.25%) and available nitrogen (174 kg/ha), medium in available phosphorus (20.5 kg/ha) and potassium (186 kg/ha). The experiment was conducted using a Randomized Block Design with ten treatments and was replicated thrice. Treatments include: atrazine 1.0 kg/ha pre-emergence application (PE) followed by (fb) one hand weeding (HW) at 30 days after seeding (DAS), atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha post-emergence application (PoE), atrazine 1.0 kg/ha PE fb topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE fb halosulfuron-methyl 67.5 g/ha PoE, atrazine 1.0 kg/ha PE fb 2,4-D amine salt 580 g/ha PoE, atrazine 1.0 kg/ha PE fb tank mix of tembotrione 60 g + 2,4-D amine salt 290 g/ha PoE, atrazine 1.0 kg/ha PE fb tank mix of topramezone 15 g + 2,4-D amine salt 290 g/ha PoE, atrazine 1.0 kg/ha PE fb tank mix of halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE, hand weeding twice at 15 and 30 DAS and weedy check.

Maize hybrid ‘DHM–117’ was sown at a spacing of 60 x 20 cm, on 19th November 2017 and 11th November 2018. After maize harvest, greengram variety ‘IPM–02–14’ was sown in undisturbed layout of maize experimental plots as a succeeding crop after ploughing the maize field, at a spacing of 30 x 10 cm to study the residual effect of pre and post-emergence herbicides applied to maize on the weeds and greengram. Gross plot size of the experimental unit was 5.4 x 4.6 m. Recommended doses of 240 kg N, 80 kg P and 80 kg K/ha for maize and 20 kg N and 50 kg of P/ha for greengram was applied using urea, single super phosphate and muriate of potash to all the plots uniformly. The pre-emergence application of herbicide was done within 24 hours after sowing and post-emergence application of herbicide was done at 21 DAS of maize. Weeding was not done in greengram plots since the crop was raised to study the residual effect of herbicides applied to maize.

The weed population was counted with the help of 0.5 m² quadrat thrown randomly at two places in each plot and expressed as weed density (no./m²). While recording weed density, weeds were harvested from each of the quadrat for estimating the weed biomass. Different weed species collected for assessing the density of weeds were dried separately in a hot air oven at 65°C till constant dry weight was reached and expressed as weed biomass (g/m²). Five randomly selected plants were tagged in each treatment, from each replication in the net plot area and used for making observations on yield attributes of maize and greengram. Due to large variation in values of weed density and biomass, the corresponding data was subjected to square root transformation (\(\sqrt{\text{value}}\)) and the corresponding transformed values were used for statistical analysis as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on weeds

The predominant weed species in the experimental site were: Brachariaria ramose L., Cynodon dactylon, Dactyloctenium aegyptium (L.) Beauv, Digitaria sanguinalis (L.) Scop, amongst grasses, Cyperus rotundus L., a sedge and Boerhavia erecta L., Borrella hispida (L.) Schum., Celosia argentea L., Cleome viscosa L., Clitoria ternatea L., Commelina benghalensis L., Corchorus aestuans L., Diggera arvensis, Euphorbia hirta L., Phyllanthus niruri L., Trichedesma indicum L. and Tridax procumbens L. amongst the broad-leaved weeds.

The HW twice at 15 and 30 DAS recorded significantly lower grass weed density and biomass which was closely followed by atrazine 1.0 kg/ha PE fb topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE fb one HW at 30 DAS, without any significant difference among themselves. Sequential application of herbicides might have resulted in effective control of grass weed density and biomass and was equally effective to that of twice HW as also reported earlier by Puscal et al. (2018).

Sedge’s density and biomass at 80 DAS of maize was significantly lower with atrazine 1.0 kg/ha PE fb halosulfuron-methyl 67.5 g/ha PoE which might be due to greater efficacy of halosulfuron-methyl in reducing the sedges than other PE or PoE herbicides. HW twice at 15 and 30 DAS, atrazine 1.0 kg/ha PE fb halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE, atrazine 1.0 kg/ha PE fb topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE fb one HW at 30 DAS were the next best treatments in reducing the sedges density and biomass without any significant difference among themselves.

Hand weeding twice at 15 and 30 DAS and atrazine 1.0 kg/ha PE fb one HW at 30 DAS were equally effective in significantly lowering broad-leaved weed density and biomass. Broad-leaved weeds were not observed in the rest of the weed management treatments during the study due to greater efficacy of PE application of atrazine 1.0 kg/ha in controlling the broad-leaved weeds in the initial stages of maize growth whereas and their management later stages of crop growth was done by
PoE herbicides or HW done at 30 DAS of resulting in absence of broad-leaved weeds in these treatments even at 80 DAS of maize.

The total weed density and biomass at 80 DAS was lower with HW twice at 15 and 30 DAS, which was at par with atrazine 1.0 kg/ha PE fb topazmone 30 g/ha PoE, atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE fb one HW at 30 DAS. Lower total weed density and biomass might be attributed to effective control of weeds with two HW or due to initial flush of weeds management by PE application of atrazine whereas and prevention of the emergence and establishment of weeds at later stages of crop growth due to the PoE herbicides as reported by Dharam et al. (2018) and Sandeep et al. (2018).

At 80 DAS, (Table 1) higher weed control efficiency (WCE) was recorded with HW twice at 15 and 30 DAS, which was followed by atrazine 1.0 kg/ha PE fb topazmone 30 g/ha PoE, atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE fb one HW at 30 DAS. Reduced weed density and biomass from the initial stages of crop growth with these treatments might have resulted in higher WCE as observed earlier by Mukherjee and Rai (2015).

### Table 1. The influence of different weed management treatments on weed density and biomass of three categories of weeds in maize at 80 days after seeding (DAS)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grasses (no./m²)</th>
<th>Sedges (no./m²)</th>
<th>BLW (kg/ha)</th>
<th>Total (kg/ha)</th>
<th>Grasses (g/m²)</th>
<th>Sedges (g/ha)</th>
<th>BLW (g/ha)</th>
<th>Total (g/ha)</th>
<th>WCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrazine 1.0 kg/ha PE fb one HW at 30 DAS</td>
<td>3.0 (2.4)</td>
<td>3.5 (3.4)</td>
<td>4.8 (4.3)</td>
<td>4.6 (4.6)</td>
<td>3.8 (3.7)</td>
<td>1.6 (1.7)</td>
<td>1.7 (1.6)</td>
<td>6.0 (6.0)</td>
<td>82.7</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha PoE</td>
<td>2.9 (2.3)</td>
<td>3.5 (3.4)</td>
<td>1.0 (1.0)</td>
<td>4.5 (3.9)</td>
<td>4.6 (4.5)</td>
<td>3.8 (3.6)</td>
<td>1.0 (1.0)</td>
<td>5.8 (5.7)</td>
<td>83.8</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha PE fb topazmone 30 g/ha PoE</td>
<td>2.6 (2.2)</td>
<td>3.4 (3.3)</td>
<td>1.0 (1.0)</td>
<td>4.2 (3.8)</td>
<td>4.5 (4.4)</td>
<td>3.7 (3.6)</td>
<td>1.0 (1.0)</td>
<td>5.8 (5.6)</td>
<td>84.0</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha PE fb halosulfuron-methyl 67.5 g/ha PoE</td>
<td>8.5 (8.7)</td>
<td>8.7 (8.7)</td>
<td>1.0 (1.0)</td>
<td>8.7 (8.7)</td>
<td>10.5 (10.7)</td>
<td>8.2 (8.2)</td>
<td>1.0 (1.0)</td>
<td>10.6 (10.6)</td>
<td>45.5</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha PE fb 2,4-D amine salt 580 g/ha as PoE</td>
<td>7.6 (7.7)</td>
<td>7.7 (7.7)</td>
<td>1.0 (1.0)</td>
<td>10.3 (10.9)</td>
<td>9.2 (9.2)</td>
<td>5.7 (5.8)</td>
<td>1.0 (1.0)</td>
<td>10.8 (10.8)</td>
<td>43.3</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha as PoE</td>
<td>4.9 (5.3)</td>
<td>6.2 (6.4)</td>
<td>1.0 (1.0)</td>
<td>7.9 (8.0)</td>
<td>7.5 (6.3)</td>
<td>4.9 (4.6)</td>
<td>1.0 (1.0)</td>
<td>8.9 (7.7)</td>
<td>61.7</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha as PoE</td>
<td>4.9 (5.3)</td>
<td>6.1 (6.1)</td>
<td>1.0 (1.0)</td>
<td>7.8 (7.9)</td>
<td>7.3 (6.2)</td>
<td>4.6 (4.4)</td>
<td>1.0 (1.0)</td>
<td>8.6 (7.5)</td>
<td>64.0</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha as PoE</td>
<td>4.9 (5.1)</td>
<td>6.1 (6.1)</td>
<td>1.0 (1.0)</td>
<td>7.8 (7.9)</td>
<td>7.3 (6.2)</td>
<td>4.6 (4.4)</td>
<td>1.0 (1.0)</td>
<td>8.6 (7.5)</td>
<td>64.0</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha as PoE</td>
<td>7.8 (8.1)</td>
<td>3.4 (3.2)</td>
<td>1.0 (1.0)</td>
<td>8.5 (8.7)</td>
<td>9.6 (7.9)</td>
<td>3.2 (3.1)</td>
<td>1.0 (1.0)</td>
<td>10.1 (8.4)</td>
<td>50.5</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha as PoE</td>
<td>8.5 (8.3)</td>
<td>2.4 (2.5)</td>
<td>1.5 (1.5)</td>
<td>4.1 (3.9)</td>
<td>4.5 (4.4)</td>
<td>4.2 (4.2)</td>
<td>3.1 (3.1)</td>
<td>1.5 (1.5)</td>
<td>5.5 (5.4)</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha as PoE</td>
<td>2.5 (3.5)</td>
<td>2.1 (3.7)</td>
<td>2.4 (3.7)</td>
<td>1.5 (1.3)</td>
<td>2.0 (1.6)</td>
<td>1.3 (1.3)</td>
<td>19.4 (19.2)</td>
<td>8.0 (8.7)</td>
<td>1.0 (1.7)</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha as PoE</td>
<td>9.6 (9.5)</td>
<td>9.5 (9.5)</td>
<td>3.4 (3.5)</td>
<td>13.4 (13.7)</td>
<td>12.3 (12.6)</td>
<td>10.6 (10.7)</td>
<td>6.7 (6.4)</td>
<td>3.4 (3.5)</td>
<td>14.3 (13.0)</td>
</tr>
<tr>
<td>Atrazine 1.0 kg/ha as PoE</td>
<td>0.67 (0.62)</td>
<td>0.62 (0.48)</td>
<td>0.48 (0.43)</td>
<td>0.43 (0.68)</td>
<td>0.56 (0.58)</td>
<td>0.68 (0.45)</td>
<td>0.48 (0.23)</td>
<td>0.20 (0.52)</td>
<td>0.64 (0.52)</td>
</tr>
</tbody>
</table>

Data in parentheses are original values, which were transformed to arcsin and analysed statistically; PE= Pre-emergence application; PoE: Post-emergence application; fb: followed by; HW: Hand weeding
Phytotoxicity on succeeding greengram

Phytotoxicity was not observed on succeeding greengram crop at 10th and 15th day after sowing due to various pre and post emergence herbicides applied in maize. Similar results of post emergence application of tembotrione in maize with no residual phytotoxicity on succeeding wheat and mustard crop was reported by Dharam et al. (2018).

Weed density and biomass in succeeding greengram

At 20 DAS of greengram lower grasses weed density and biomass (Table 3) was recorded with HW twice at 15 and 30 DAS, which was at par with atrazine 1.0 kg/ha PE fb one HW at 30 DAS, atrazine 1.0 kg/ha PE fb topramezone 30 g/ha PoE and atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha PoE. The density and biomass of sedges were lower with atrazine 1.0 kg/ha PE fb halosulfuron-methyl 67.5 g/ha PoE, which was at par with atrazine 1.0 kg/ha PE fb halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE, which indicated that recommended dose or half of the recommended dose of halosulfuron-methyl is effective in controlling the sedges in maize-greengram cropping system, whereas the broad-leaved weed density and biomass were lower with atrazine 1.0 kg/ha PE fb topramezone 30 g/ha PoE, which was comparable with atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha PoE, HW twice at 15 and 30 DAS and atrazine 1.0 kg/ha PE fb one HW at 30 DAS. Weedy check recorded significantly highest density and biomass of grasses, sedges and broad-leaved weeds in the succeeding greengram.

The total weed density and biomass in greengram at 20 DAS (Table 3) due to the residual effect of weed management practices imposed in preceding maize, was lower with atrazine 1.0 kg/ha PE fb topramezone 30 g/ha PoE , which was in parity with hand weeding twice at 15 and 30 DAS, atrazine 1.0 kg/ha as PE fb one HW at 30 DAS and atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha PoE, without significant differences amongst them due to better control of weeds under these treatments in maize that might have resulted in the lower weed seedbank in the soil, which in turn reduced the density and dry weight of weeds in succeeding greengram as also reported by Verma et al. (2009).

Greengram growth parameters, yield attributes and yield

The growth parameters, yield attributes and yield of succeeding greengram differed significantly due to different weed management practices.
Table 3. The weed density and biomass at 20 days after seeding (DAS) of greengram as influenced by weed management treatments applied in preceding maize

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weed density (no./m²)</th>
<th>Weed biomass (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grasses</td>
<td>Sedges</td>
</tr>
</tbody>
</table>

Atrazine 1.0 kg/ha as PE  
b: one HW at 30 DAS
- Grasses
- Sedges
- BLW

Atrazine 1.0 kg/ha as PE  
b: tembrotione 120 g/ha as PoE
- Grasses
- Sedges
- BLW

Atrazine 1.0 kg/ha as PE  
b: topramezone 30 g/ha as PoE
- Grasses
- Sedges
- BLW

Atrazine 1.0 kg/ha as PE  
b: halosulfuron-methyl 67.5 g/ha as PoE
- Grasses
- Sedges
- BLW

Hand weeding twice at 15 and 30 DAS
- Grasses
- Sedges
- BLW

Weedy check
- Grasses
- Sedges
- BLW

LSD (p=0.05)

Data in parentheses are original values, which were transformed to square roots and analysed statistically; PE: Pre-emergence application; PoE: Post-emergence application; b: followed by; HW: Hand weeding

Table 4. Influence of different weed management treatments applied in maize on yield attributes and yield of succeeding greengram

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination (%)</th>
<th>Plant height (cm)</th>
<th>Dry matter production (kg/ha)</th>
<th>No. of pods/plant</th>
<th>No. of seeds/pod</th>
<th>Seed index (g)</th>
<th>Seed yield (kg/ha)</th>
<th>Haulm yield (kg/ha)</th>
</tr>
</thead>
</table>

Atrazine 1.0 kg/ha as PE  
b: one HW at 30 DAS
- Grasses
- Sedges
- BLW

Atrazine 1.0 kg/ha as PE  
b: tembrotione 120 g/ha as PoE
- Grasses
- Sedges
- BLW

Atrazine 1.0 kg/ha as PE  
b: topramezone 30 g/ha as PoE
- Grasses
- Sedges
- BLW

Atrazine 1.0 kg/ha as PE  
b: halosulfuron-methyl 67.5 g/ha as PoE
- Grasses
- Sedges
- BLW

Hand weeding twice at 15 and 30 DAS
- Grasses
- Sedges
- BLW

Weedy check
- Grasses
- Sedges
- BLW

LSD (p=0.05)

*PE= Pre-emergence application; PoE= Post-emergence application; b: followed by; HW: Hand weeding
implemented in maize (Table 4). The higher growth parameters, yield attributes, seed and haulm yield of greengram was recorded with hand weeding twice at 15 and 30 DAS, which was closely followed by application of atrazine 1.0 kg/ha PE fb one HW at 30 DAS, atrazine 1.0 kg/ha PE fb topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE fb tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE fb halosulfuron-methyl 67.5 g/ha PoE, in the order of descent, without significant disparity among them (Table 4). This might be due to higher WCE in the respective treatments in both maize and greengram, which might have lead to lower weed density and biomass in the succeeding greengram that in turn favored greengram to accumulate higher dry matter, enhanced synthesis and translocation of assimilates to developing pods and seeds that may lead to higher yields of succeeding greengram.

The present study has revealed that atrazine 1.0 kg/ha PE fb topramezone 30 g/ha or tembotrione 120 g/ha PoE were the most effective weed management treatments that effectively managed weeds and increased the productivity of winter maize and succeeding summer greengram. These treatments may be used for effective management of weeds in maize at times of labor shortage, and without any residual effect on succeeding greengram.

REFERENCES


