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Impacts of tillage and herbicide mixture on weed interference, agronomic productivity and profitability of a maize – Wheat system in the North-western Indo-Gangetic Plains

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ABSTRACT

Weeds comprising of annual monocotyledons, dicotyledons and perennial *Cyperus rotundus* L. (hereafter referred to as nutsedge) are important constraints in maize-wheat production system in India. They can cause yield losses of 25–30% in maize and 10–25% in wheat. Recently, continuous use of selective herbicides has led to an increase of nutsedge and other annual weeds in maize. There is need for a broad-spectrum weed control strategy that includes control of nutsedge in maize. Herbicide mixtures, containing a nutsedge killer partner herbicide may prove to be more effective for this. Imazethapyr among herbicides available in India possesses nutsedge-killing action, but the tolerance of maize to this herbicide, which is usually recommended for application as post-emergence in soybean and groundnut, is variable. We observed dose-dependent selectivity/tolerance of maize to imazethapyr when applied as post-emergence in a previous trial. Imazethapyr's pre-emergence application may prove more useful in offering selectivity to maize, but is hardly studied. In addition, its residual/carry-over effect may lead to weed control in following wheat crops grown in sequence with maize, economizing production costs of the maize-wheat system. Therefore, this experiment was designed to evaluate the efficacy of imazethapyr against weeds including nutsedge, and its selectivity in maize crops when applied as pre-emergence in tank-mixture with pendimethalin; to compare these tank-mixtures effects with that of the sequential applications of pendimethalin (pre-emergence) and imazethapyr (post-emergence) in maize; and to evaluate their residual actions combined with tillage and crop residue in wheat under a maize- wheat system. The application of pre-emergence tank-mixture of pendimethalin 0.75 kg a.i. ha^{-1} + imazethapyr 0.050 kg a.i. ha^{-1} caused significant reductions in densities of broad-leaved (30%), nutsedge (45.2%), grassy (79.7%) and total weeds (49.1%) compared with un-weeded control (UWC) in maize. It reduced total weed dry weight by 58.3% and gave 56.1% higher maize yields than UWC. Among the tillage treatments adopted in the wheat crop, zero tillage (ZT) + residue (R) resulted in 14.0% greater reductions in weed dry weight and 6.9% higher wheat yields than conventional tillage (CT). It increased maize-wheat system productivity by 5.4% and 7%, respectively over CT and ZT without residue. The application of a tank-mixture of pendimethalin + imazethapyr gave 2.9% lower system productivity, but 8.2% higher net returns than the weed-free control, reducing the weed seed bank by 65% at 0–15 cm soil layer in two years. The application of this tank-mixture (in maize), followed by ZT + residue (in wheat) was more remunerative and could lead to better weed control with 25% and 50% lower doses of pendimethalin and imazethapyr, respectively, and 50% reduction in application cost. This practice can be adopted in maize-wheat system under irrigated conditions in the North-western Indo-Gangetic Plains of India, and in similar agro-ecologies of the tropics and sub-tropics. This result can also be applicable to cropping systems like maize – mustard, maize – barley/oat, subject to further evaluation and refinement under field conditions.

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1. Introduction

In India, maize (*Zea mays* L.) is grown on 9.5 million hectares with an annual production of 24.5 million tonnes (USDA, 2017). It is the third most important food crop after rice and wheat. The maize – wheat cropping system, occupying 1.83 million ha area is the third most important cropping system after rice-wheat and rice–rice system, and ranks first among the maize-based cropping systems (Saad et al., 2015). It contributes nearly 3% to the national food basket after rice–wheat and rice–rice system. Maize's adaptability to diverse environments and seasons is unmatched by any other crop. It can be a potential driver for crop diversification of the most dominant rice-wheat system, occupying ~10.5 million ha area in the Indo-Gangetic Plains (IGP) of India (Hobbs and Gupta, 2003; Humphreys et al., 2010). Recently, the sustainability of rice-wheat system is under threat due to several problems related to water, nutrients, energy, weeds and environment encountered with the cultivation of rice. Maize-wheat system could be a viable alternative to the rice-wheat system (Gupta et al., 2003; Ram et al., 2012; Bhattacharyya et al., 2013; Das et al., 2013) that can ensure environment-friendly crop production and food and nutritional security.

The farmers in the IGP usually follow a conventional till (CT) maize − CT wheat cropping system, which involves 4–5 ploughings for land preparation before sowing of each crop. Excessive tillage requires higher energy (Erenstein and Laxmi, 2008) can produce ill-effects for soil health. Recently, the improved versions of seed drill (i.e.turbo/happy seeder) are available in India, which can facilitate the sowing of wheat in untilled soils with residues of previous crops. Farmers are gradually adopting this and the area of CT maize–zero till (ZT) wheat system is on the increase. The ZT wheat is sown in around 2.5 million ha after the harvests of rainy season (*kharif*) crops such as rice, maize, cotton, pigeon pea, pearl millet and cluster bean. It saves time and cost (~30%) for land preparation (US$ 37.06–44.47 ha^{-1}) and irrigation, reduces diesel consumption by 50–60 L ha^{-1} (Erenstein and Laxmi, 2008; Saad et al., 2016), and ensures timely sowing of wheat, leading to higher wheat yield and farm income.

The average yields of maize (~2.58 Mg ha^{-1}) and wheat (~3.0 Mg ha^{-1}) are low in India (USDA, 2017). Weeds cause yield losses by 20–30% and 10–25%, respectively in maize and wheat. Weeds, germinating in 3–4 flushes during rainy season are a major constraint in maize. Besides, continuous use of selective herbicides has led to insurgence of nutsedgein maize, soybean (Kumar et al., 2012; Younesabadi et al., 2013) and other rainy season crops. A single herbicide is not adequate for controlling diverse weeds. Herbicides that kill annual weeds as well as nutsedge are lacking, but could be cost-effective alternatives for weed control in maize. The maize crop's tolerance to herbicides also limits the choice of herbicides. A herbicide mixture/tank-mixture, containing a nutsedge-killer partner herbicide may be more effective in controlling diverse weeds including nutsedge, and needs to be investigated. In India, recently, a post-emergence herbicide imazethapyr recommended exclusively for soybean and groundnut, has been found effective against nutsedge. It can be tried for nutsedge control in maize, but the tolerance of maize to imazethapyr is variable and variety-specific (Van Wyk and Reinhardt, 2000). The post-emergence applications of imazethapyr at 0.075 and 0.100 kg a.i.ha^{-1} were found phytotoxic to maize in a previous trial (Authors' observations). Imazethapyr was toxic to even herbicide-tolerant soybean crop (Mills and Witt, 1989). But, Curran et al. (1991) observed no injury to maize, even when maize plants were exposed to imazethapyr at three times of the recommended dose (i.e. 0.21 kg a.i. ha^{-1}) for tolerant crops. To offer more selectivity/tolerance to maize crop, the pre-emergence application of imazethapyr can be useful due to depth-protection, but is hardly studied. Therefore, in this study, its time (pre-emergence instead of usual post-emergence) and dose (0.050 instead of usual 0.1 kg a.i.ha^{-1} applied in soybean and groundnut) of application were altered in order to achieve greater selectivity to maize and better weeds/nutsedge control. Herbicide may produce reactive oxygen species (ROS) like superoxide ion ($O_2^{\bullet-}$), hydrogen peroxide (H_2O_2) (Arora et al., 2002; Qian et al., 2011), which can be related to stress levels that crop experiences due to herbicides. Crops respond simultaneously by increasing the activities of anti-oxidant enzymes, namely, superoxide dismutase (SOD), catalase (CAT) or ascorbate peroxidase (APX) that can scavenge the stress-effects (Blokhina et al., 2002; Hajebiet al., 2016). Studying the activity of ascorbate peroxidase can, therefore, indicate the possible selectivity/defence mechanism whether operating in maize against imazethapyr.

Long persistence of herbicides beyond the season of application is potentially hazardous in terms of environmental impacts and injury to sensitive rotational crops. Soil pH, organic matter content and various edaphic factors influence the adsorption and persistence of imazethapyr in soil (Renner et al., 1988). The carry-over of phytotoxic residues of imazethapyr (Goetz et al., 1990) can cause injury to wheat, which is a sensitive crop grown after maize (Van Wyk and Reinhardt, 2000; Alister and Kogan, 2005). However, this may also lead to useful weed control in the following wheat crop. Tillage (Peachey et al., 2004; Anderson, 2010, Nath et al., 2017), cropping system (Clements et al., 1996; Chauhan and Johnson, 2010), fertilizers (Das and Yaduraju, 2011), dormancy breakers (Das et al., 2014), and brown manuring (Ramachandran et al., 2012) can all influence weed interference and crop yields. They can be complimentary/supplementary to the already adopted weed control/herbicide treatments in maize, and lead to integrated weed management in the maize-wheat system. Therefore, other options such as KNO_3 application before the application of tank-mixture of pendimethalin + imazethapyr, brown manuring were included in this study. The philosophy was that KNO_3 application would break dormancy (Khan and Shah, 2011; Das et al., 2014) and facilitate uniform germination of weed seeds at one time/phase. Then, the germinating weeds can be effectively controlled by the application of a selective pre-emergence herbicide. Brown manuring with *Sesbania bispinosa* (Jacq.) W.Wight (~*Sesbania*) can offer concurrent and residual effects on weeds/nutsedge and crops, and reduce herbicide use (Gupta and Seth, 2007; Ramachandran et al., 2012), but is not or less studied in maize. The populations of emerged weeds can provide an indicator of success in weed management efforts, but monitoring the seed bank may offer additional information about the long term prognosis for weed management (Sheibani and Ghadiri, 2012). This experiment was designed to evaluate the efficacy against weeds/nutsedge, and the selectivity to maize, of imazethapyr applied pre-emergence as a tank-mixture with pendimethalin, and to compare these effects with that of the post-emergence application of imazethapyr, following the pre-emergence application of pendimethalin in maize; and the residual actions of imazethapyr combined with tillage and residue on weeds and wheat in a CT maize −ZT wheat system.

2. Materials and methods

2.1. Experimental site

The field experiments were conducted under natural weed infestations in maize (rainy season)-wheat (winter) cropping system in 2010–11 and 2011–12 at the Indian Agricultural Research Institute, New Delhi. Soil (Inceptisol) was a sandy loam with pH 7.9 and organic carbon 0.52%, and medium available P (18.4 kg ha^{-1}) and available K (191.6 kg ha^{-1}) and low available N (272.6 kg ha^{-1}). The climate of the experimental field is semi-arid, sub-tropical with hot and dry summers and cold winters. The distributions of minimum and maximum temperatures and rainfall during both years are given in Fig. 1. Of the annual rainfall, 80% is received during July–September, and rest is received during December to February. Pan evaporation varies from 3.5 to 13.5 mm d^{-1} and reference evapo-transpiration from 9 to 15 mm d^{-1}. The experimental site had even topography and was irrigated with a good drainage system.