COMMENTARY

Impact of climate change on weeds in the rice–wheat cropping system

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Rice and wheat, being the staple food, play a crucial role in the food security of India. Increase in temperature, atmospheric greenhouse gases, and soil degradation and competition for land and water resources will have multiple impacts on the rice–wheat cropping system of northwest India. Atmospheric carbon dioxide (CO_2) has risen from 280 to 387 μmol mol^{-1} from 1750 to 2007, as a result of continuous anthropogenic activities; the CO_2 concentration is expected to reach 600 μmol mol^{-1} sometime around 2050 (refs 1–4). Climate change will also affect the weed communities in the rice–wheat cropping system. A review on the effect of weed growth on yield suggested losses in the range 28–74% in rice and 15–80% in wheat[5,6]. Improving weed control in farmers' field has shown to increase rice and wheat yield by 15–30%.

Northwest India annually contributes more than 50–60% of rice and wheat to the central food grain reserve, making it the 'bread basket' of the country. Therefore, if productivity of these crops is affected, Indian food security is bound to be affected. Given that the demand for food is projected to rapidly outpace increase in supply, effective weed control is a priority in this system. Important weeds of rice include *Echinochloa crus-galli*, *E. colona*, *E. glabrescens*, *Ammannia* spp., *Eragrostis* spp., *Ludwigia* sp., *Ischaemum rugosum*, *Leptochloa chinensis*, *Paspalum distichum*, *Cyperus iria*, *C. difformis*, *Fimbristylis miliacea*, *Scirpus maritimus*, *Eleocharis* spp., *Eclipta prostrata*, *Sphenoclea zeylanica* and *Monochoria vaginalis*. Important weeds of wheat include *Phalaris minor*, *Avena ludoviciana*, *Poa annua*, *Lolium temulentus*, *Chenopodium album*, *Rumex dentatus*, *R. spinosus*, *Medicago denticulata*, *Melilotus alba*, *Anagallis arvensis*, *Lathyrus aphaca*, *Fumaria parviflora*, *Vicia sativa*, *Coronopus didymus*, *Malva parviflora* and *Cirsium arvense*. Common weed management practices in the rice–wheat cropping system include soil tillage, flooding, summer ploughing, crop rotation and use of herbicides; these practices are often used in combination. Climate change is one of the many risk factors affecting rice and wheat production and weed management. Change in atmospheric CO_2, rainfall and temperature will affect weed species distribution, and prevalence within weed and crop communities. Climate change may also necessitate adaptation of agronomic practices, which in turn influence weed growth and proliferation of certain weed species. Weed management operations, for example, chemical and mechanical, could be influenced by climate change. In this note, the likely effect of climate change on the competitiveness of major weeds of the rice–wheat cropping system in northwest India and the consequences of changing climate and weed community composition for weed management have been discussed.

A mean annual surface air temperature rise of 0.3°C to 0.6°C since the 1860s across northwest India represents significant warming. This warming trend is, in general, comparable to the global mean trend of 0.5°C in the past 100 years[4]. It has been reported that temperature, atmospheric CO_2 concentration and rainfall irregularities will increase in South Asia, including northwest India[7]. This will affect weed species in different ways in the rice–wheat cropping system depending upon the photosynthetic pathways and tolerance to water stress.

The productivity of rice and wheat would decline due to the increased climate variability, particularly change in water supply and demand, and pests, including weed incidence and virulence in the long term (2050 and beyond). Under high temperature, plants with C_4 carbon fixation pathway (mostly weeds) have a competitive advantage over crop plants possessing the more common C_3 pathway[8]. Most of the weeds in rice are of C_4 type in northwest India. For a C_3 crop such as rice and wheat, elevated CO_2 may have positive effects on crop competitiveness with C_4 weeds[9,10]. But this is not always true. To date, for all crop–weed competition studies, where the photosynthetic pathway is the same, weed growth is favoured as CO_2 is increased. Therefore, the problems of *P. minor* and *A. ludoviciana* in wheat would aggravate with increase in CO_2 due to climate change. Further, the problem could be aggravated with water scarcity. Due to CO_2 enrichment, the wheat plant could gain biomass against *P. minor*. Under water stress conditions, however, *P. minor* had advantage over wheat with CO_2 enrichment[11]. Studies on the effect of CO_2 enrichment on weed species at the Directorate of Weed Science, Jabalpur revealed that a few weed species such as *Dactyloctenium aegyptium* and *E. colona* responded to elevated CO_2, but *Cyperus rotundus* and *Eleusine indica* did not respond to CO_2 enrichment. Weedy rice (*Oryza sativa* L.) responds more strongly than cultivated rice to rising CO_2 level with greater competitive ability[12], suggesting that weedy rice may become a more problematic weed in the future.

In addition to agronomic weeds, there is another category of plants that are considered noxious or invasive weeds. Many of these weeds reproduce by vegetative means, for example, *Cynodon dactylon* in rice and *Convolvulus arvensis* and *C. arvense* in wheat. These weeds may show a strong response in growth with increase in atmospheric CO_2. How rising CO_2 would contribute to the success of these weeds *in situ* is, however, not clear. Increased atmospheric CO_2 levels are likely to be accompanied by higher temperature favouring C_4 weeds over C_3 crops[9]. A similar shift in weed species composition can also be expected under erratic rainfall because of climate change. Due to sudden change in climate, environmental stress on a crop may increase and as a result the crop could become more vulnerable to attack by insect and pathogens, and less competitive with weeds. The aberrations in weather conditions not only affect crop–weed competition, but also trigger weed seed germination in several flushes causing serious weed management issues. Three flushes of *P. minor* are not uncommon in the wheat fields in northwest India, which are not controlled by a single application of herbicide.

Climate change may increase the importance of conservation agriculture, and adoption of conservation agriculture requires knowledge of local conditions and an understanding of the overall system dynamics. Glyphosate is being used as a pre-plant herbicide to kill weeds before crop sowing under conservation agriculture; however, the weeds may acquire higher tolerance to glyphosate at higher CO_2 level. A study indicated that the effectiveness of glyphosate was reduced when *Chenopodium album* was grown in an elevated CO_2 environment[13]. This suggests that glyphosate efficiency in future may decrease with increase in CO_2.

Temperature changes may result in an expansion of weeds, with some species moving/shifting to higher latitude and altitude. For instance, incidence of *I. rugosum*, which was a common weed of the tropical areas, now has a sizable area in the northern states[14]. Similarly, incidence of *R. spinosus* in wheat in northwest India has increased. Irrigation water in northwest India is increasingly become scarce and many resource–conservation technologies are recommended to conserve irrigation water; for instance, zero tillage in wheat, bed planting in rice and wheat, and dry-seeded rice. This will have consequences on weed abundance and composition. Flooding is commonly the primary cultural means to suppress weeds in rice; however, flooding effect may vary in weed species[15,16]. Alternate wetting and drying in puddled as well as dry-seeded rice may encourage weeds such as *L. chinensis*, *E. indica* and *E. prostrata*. With irrigation water becoming scarce, maintaining ponding in paddy for the first 15 days for effective weed control is likely to be increasingly difficult. Under these circumstances, where the farmer is not aware of alternative weed control, yield losses are likely to be expected.

Strategies for weed management need to be developed according to the change in the environmental conditions. Problem of resistant weeds, herbicide toxicity, and poor control of weeds with herbicide application may increase as a result of environmental change. Herbicide efficacy might be affected by raised CO_2 levels, which has been shown to increase the tolerance of weeds to herbicide[2]. Change in temperature and CO_2 concentration may alter transpiration, the number of leaf stomata, or the thickness of the leaf, which may affect the absorption and translocation of herbicides. In C_3 plants, increased concentration of leaf starch under elevated CO_2 levels might reduce herbicide efficacy. Greater CO_2 concentration may stimulate below ground growth relative to above ground growth[17]. This will favour rhizome and tuber growth of perennial weeds, in particular, those following the C_3 photosynthetic pathway, which may render their control more difficult. This means that the problem of perennial weeds in rice and wheat may increase in the near future. These weeds could be controlled through integrated approaches that combine preventive and control measures. Management practices will have a significant bearing on the control of troublesome weeds[18].

Integrated weed management strategies need to be developed which target the prevention of weed invasion, recruitment and reproduction. Such strategies may include combination of optimal fertilizer schedule, summer ploughing, crop rotation, land preparation, modifying plant geometry, stale seedbed technique, planting time, seed rate and use of weed-competitive cultivars[18]. Knowledge of weed ecology and biology could be used as a tool for effective weed management in futuristic climate change. Timely effort to fill the research gap on environment, management and weed interactions is needed for the sustainability of the rice–wheat cropping system in northwest India. Therefore, there are strong reasons for expecting climate change to alter weed management, and the management approaches must be adapted to take this into account. Integrated novel approaches must be developed to assist farmers in coping with the challenge of weed control in future.

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