

Original Research Article

IMPACT OF CLIMATE CHANGE ON WEEDS AND HERBICIDE EFFICACY

Abstract:

Climate change is the change in statistical distribution of weather pattern that lasts for an extended period of time. There are several components of these climate changes occurring globally that includes uneven rainfall, droughts, floods, warming of atmosphere etc. These are the most important challenges influencing natural ecosystems, agricultural productivity and food security. Climate change is not only influencing crop plants and forests directly but can also impact the pests of these crops. Weeds respond to climate change by changing-in the duration of their life cycles, population dynamics and shift to new habitats and become a potential competitor to crop plants thereby reducing the production and productivity of crops. Elevated temperature and elevated CO₂ level in the environment interfere with herbicide activity, which and affects the herbicide absorption, translocation and thereby reduces the efficacy of the applied herbicide. Weeds' resistance to herbicides will-may probably increase due to morefurther aggressive growth of weeds in future climate conditions, which can cause a decline in the efficacy of routinely used herbicides.

Key words: Climate change, Weeds, Weed Invasion, Crop-Weed Competition, Herbicide efficacy

Introduction

Climate is the synthesis of weather conditions in a given area, characterized by long term statistics for the meteorological elements in that area. Generally, the quantities measured are surface variables, such as temperature, precipitation, and wind. More broadly, the "climate" is the description of the state of the climate system (IPCC, 1995).

Climate change is the change in statistical distribution of weather pattern that lasts for an extended period of time. It is a tribute, directly or indirectly to human activity that alters the

Formatted: Indent: Left: 0"

Comment [BD1]: May include depletion of ozone layer in the stratosphere

Comment [BD2]: In (removed)

Comment [BD3]: their

Comment [BD4]: level in the environment

Comment [BD5]: which

Comment [BD6]: further

composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period (UNFCCC, 1994). Since the industrial revolution began around 1750, human activities have contributed substantially to climate change by adding CO₂ and other heat trapping greenhouse gases to the atmosphere (CH₄, NO₂, SO₂ and CFC₂ etc). These gas emissions have increased the greenhouse effect and caused earth's surface temperature to rise. Projections suggest 2.4 - 6.4 °C increase of global average temperature by the end of 21st century (IPCC, 2007).

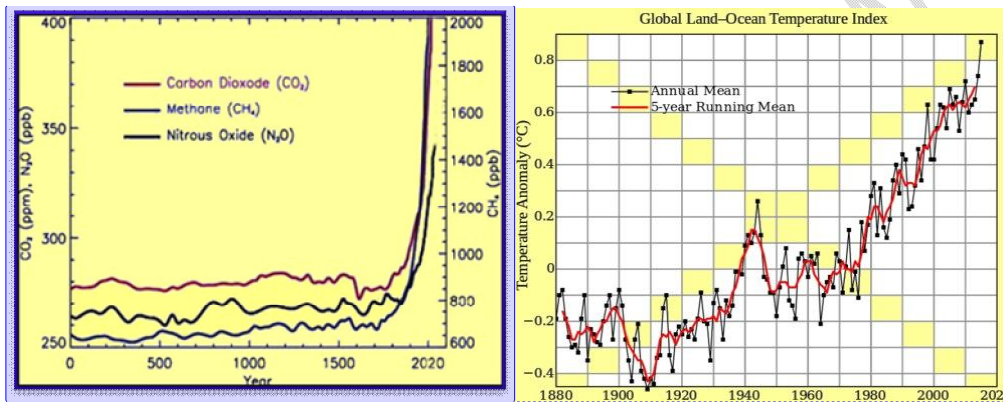


Fig 1. Global Land Ocean temperature index

Crop production and agronomic practices involving weed management and pest control may be severely affected by these altered abiotic conditions primarily caused by changes in climate and climate variability (Dukes *et al.*, 2009; Singer *et al.*, 2013). Warmer and wetter climates not only affect weed growth but also change the chemical properties of certain herbicides; thereby altering their performance on weeds and their control (Dukes *et al.*, 2009).

Comment [BD7]: Put Figure name/title?????

Comment [BD8]: Acknowledge the source of the figures if any,

Comment [BD9]: ;

Comment [BD10]: the

Impact of climate change on weeds

~~For Achieving~~ sustainable crop production in unpredictable environments necessitates a holistic approach that focuses on not only increasing crop productivity but also effective management of agricultural pests such as weeds. Hence, to understand the effects of climate change on weed growth and development, ~~Ziska and Goins et al. (2007)~~ conducted an experiment at agricultural research station, Beltsville (USA) to study the effect of different CO₂ concentration on vegetative and qualitative characteristics of poison ivy (*Toxicodendron radicans*) and the results revealed that there was higher leaf area (6,568 cm² plant⁻¹), leaf weight (43.3 g plant⁻¹), stem weight (87.1 g plant⁻¹), rhizome length (851 cm), number of rhizomes plant⁻¹ (2.25) and urushiol content (78.1 mg) at 600 μmol mol⁻¹ of CO₂ concentration which is much higher than CO₂ concentration of 300 μmol mol⁻¹ condition. Increased CO₂ concentration not only affects crop plants by increasing the weed growth but also affects human health ~~by secreting through the secretion o some of~~ the harmful chemicals like urushiol in poison ivy which is responsible for causing dermatitis in human beings.

Table 1. Annual increase in global warming

Gas	Current concentration	Annual increase (%)	Contribution to global warming (%)
CO ₂	413.2 ppm	1.6	40-50
CH ₄	1.86 ppm	1.2	20-25
CFC's	0.24 ppb	3.0	15-20
N ₂ O	331 ppb	1.0	5-10

There were 4.2 and 17.6 per cent increase in photosynthetic rate in purple nutsedge and yellow nutsedge, respectively. They/ ~~Ziska and Goins (2007)~~ also observed reduced transpiration and conductance under elevated CO₂ conditions and ~~they~~ even studied the response of purple nutsedge and yellow nutsedge growth variables to ambient and elevated CO₂ conditions. ~~and Their~~ results revealed that there were 8.1, 4.0, 31.1 and 20.0 per cent increase in number of tillers/plant, number of leaves/plant, leaf area (cm²/plant) and root length (cm), respectively in purple nutsedge and 7.5, 8.2, 1.9 and 1.2 per cent ~~surge in the~~ number of tillers/plant, number of leaves/plant, leaf area (cm²/plant) and root length (cm), respectively in yellow nutsedge in the experiment conducted

Comment [BD11]: Achieving

Comment [BD12]: Ziska and Goins (2007) instead of Ziska et al

Comment [BD13]: an

Comment [BD14]: through the secretion of

Comment [BD15]: Put the authors' name, check the publication year

Comment [BD16]: Their

in Auburn University, Alabama (USA) the response of purple nutsedge and yellow nutsedge to ambient and elevated CO₂ conditions (Rogers *et al.* 2008).

Comment [BD17]: Either Justify the sentence or remove....

Kumar Sushilkumar and Varshney (2010) conducted an experiment at ICAR-Directorate of Weed Research, Jabalpur to study the estimated infested area by parthenium in India during different decades since 1955, and there was only 0.5 ha area infestation by parthenium in India during 1955-1960 and up to the end of 2001-2009, the infestation was increased to 18.78 m ha to non agricultural lands and 14.25 m ha to crop lands and 2.0 m ha to forest lands.

Comment [BD18]: "Kumar" instead of Sushilkumar

Comment [BD19]: Put (space)

Comment [BD20]: an

Comment [BD21]: Million hectare??? Mention clearly..

Table 2. Impact of climate change on land

Period	Infested non-agricultural lands (m ha)	Crop land (m ha)	Forest land (m ha)	Total infested area (m ha)
1955-1960	0.5	0	0	0.5
1961-1970	3.0	0	0	3.0
1971-1980	4.5	0.5	0	5.0
1981-1990	6.0	1.0	0	7.0
1991-2000	7.5	2.0	0.5	10.0
2001-2009	18.78	14.25	2.0	35.0

Lee (2011) conducted an experiment in 2011 at Konkuk University, South Korea to study the effect of photosynthetic rates of *Chenopodium album* under different climatic conditions and the results revealed that there was increased photosynthetic rate in treatment with combined conditions of 4⁰C elevated temperature and 750 ppm of CO₂ over 4⁰C elevated temperature with ambient CO₂. It, this clearly indicates that, the elevated CO₂ conditions boost up the photosynthetic rate in the weeds or in general plants.

Comment [BD22]: It clearly indicates

Understanding the effects of climate change on weed growth and herbicide activity is important to optimize herbicide applications for the effective control of weeds control in future. Hence, Manea *et al.* (2011) also conducted an experiment at Macquarie University, Sydney (Australia) to study the effect of ambient and elevated CO₂ on grassy weeds. Here they examined 3 different grassy weeds those were *Chloris gayana*, *Eragostis curvula* and *Paspalum dilatatum* and the

Comment [BD23]: control of weeds

Comment [BD24]: also

results revealed that there were increase in total biomass (g/plant) by 39, 83 and 59 per cent, respectively under elevated CO₂ concentration of about 750 ppm.

Jabran (2016) conducted experiment at Adnan Manders University, Aydin (Turkey), to study the effect of normal and elevated carbon dioxide on the fresh weight and dry weight of *Potentilla recta* L. and the results revealed that there was higher fresh weight (3.5 g/plant) and dry weight (1.0 g/plant) of *Potentilla recta* L. was observed under elevated CO₂ (800-850 ppm) conditions over the normal one (400 ppm).

Four different treatments were undertaken to study the effect of different climatic conditions on growth and biomass of *Hordeum murinum* (2 years average data), those includes control or ambient environment (CO₂= 400-450 ppm; temperature 20/10 °C day/night), elevated temperature (CO₂= 400-450 ppm; temperature 25/15 °C day/night), high CO₂ + elevated temperature (CO₂= 800-900 ppm; temperature 25/15 °C day/night) and lastly high CO₂ (CO₂= 800-900 ppm; temperature 20/10 °C day/night) and the results revealed that there was increased chlorophyll content (47.1), number of leaves (126.0), plant height (72.9 cm), fresh weight (55.1 g/plant), dry weight (7.1 g/plant) and leaf area (4476.5 cm²/plant) in treatment with high CO₂ + elevated temperature over other treatments in the experiment conducted in Adnan Manders University, Aydin (Turkey) (Jabran *et al.*, 2018).

Impact of climate change on Crop-Weed Competition

Since climate change imposes new limitations on resources essential to plant growth, crop weed interactions and crop losses from weeds are likely to be affected. To know what is the impact of climate change on crop weed competition, Kumar *et al.* (2014) conducted an experiment at ICAR-Directorate of Weed Research, Jabalpur to study the effect of CO₂ concentrations on growth and development of chickpea, *Lathyrus sativus* and *Medicago polymorpha*. The results revealed that there was 5.88 and 10.11 folds increase in number of pods/plant and fresh weight of pods (g/plant), respectively in *Medicago polymorpha* under elevated CO₂ over the ambient CO₂. This increase in growth and development of *Medicago* is much higher than Chickpea and *Lathyrus sativus*. Hence, from this we can conclude that weeds gain more advantage from elevated CO₂ than the crop plants and they also studied the effect of CO₂ concentrations on nodulation (80 DAS) of chickpea, *Lathyrus sativus* and *Medicago polymorpha*, and the results revealed that there was 4.24 folds increase in

fresh weight of nodules (g/plant) in *Medicago* which was much higher than chickpea and *Lathyrus sativus* under elevated CO₂ condition.

Gozde and Dogan (2015), conducted an experiment at Adnan Manders University, Aydin (Turkey) to study the fresh weight of wheat and weeds as affected by CO₂. Here they have considered four different weed species those were wild oat, canary grass, bedstraw and wild mustard and they have observed 1.7, 3.2, 3.7 and 2.7 folds increase in fresh weight (g pot⁻¹), respectively under elevated CO₂ (750-800 ppm) condition which was much higher than wheat.

Impact of climate change on herbicide efficacy

Successful weed management relies not only on the chemical properties of herbicides but also on its interaction with the plant and the environment. Besides plant morphologic and anatomic characteristics, environmental conditions play a pivotal role in determining the efficacy of herbicides at the time of application. Coetzer (2001) conducted experiment at Kansas State University, USA to study the effect of temperature regimes on efficacy of glufosinate. They reported that sinceas there was an increase in temperature, there was visible injuriesreduced visible injury on weeds have diminished even at higher dosage of chemical that is at 820 (g ha⁻¹). There were only 78, 73 and 70% visible injury upon application of glufosinate at 31/26 for control of palmer amaranth, redwood pigweed and common water hemp, respectively which is much lesser than the temperature regime of 21/16.

Comment [BD25]: the visible injuries on weeds have diminished

Kumar *et al.* (2011) conducted experiment at ICAR-Directorate of Weed Research, Jabalpur to study the effect of elevated CO₂ and temperature on efficacy of sulfosulfuron (25.0 g a.i./ ha) on *Phalaris minor*. They reported that there was 25% survival rate under elevated CO₂, 40% survival rate under elevated temperature and there was 60% survival rate under combined effect of elevated CO₂ and temperature.

In an experiment conducted by Naidu (2015) at ICAR-Central Tobacco Research Institute, Rajahmundry (Andra Pradesh) to study the efficacy of different herbicides at ambient and elevated CO₂ conditions, there was three, nine, seven and five days delay in complete death of *Chinopodium album*, *Phalaris minor*, *Avena fatua* and *Amaranthus viridis*, respectively upon application of glyphosate, isoproturon, clodinafop and 2,4-D under elevated CO₂ (550 ppm) over ambient CO₂ (380 ppm) conditions. in the experiment conducted by Naidu (2012) at ICAR Central Tobacco Research

Comment [BD26]: 2015 instead of 2012

Comment [BD27]: In an experiment conducted by Naidu (2012) at ICAR-Central Tobacco Research Institute, Rajahmundry (Andra Pradesh) to study the efficacy of different herbicides at ambient and elevated CO₂ conditions

Institute, Rajahmundry (Andhra Pradesh) to study the efficacy of different herbicides at ambient and elevated CO₂ conditions.

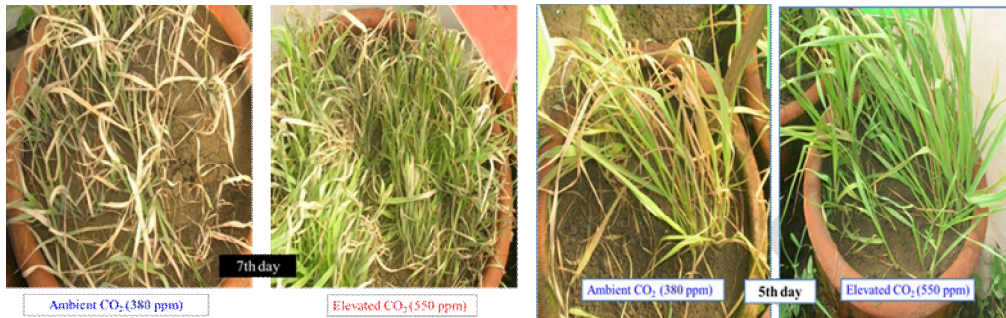


Fig 2.

Comment [BD28]: Put the name of the figures and acknowledge the source of the figures if any

Herbicides have become the major tools for weed management because of their simplicity in use, greater efficacy and more importantly, due to the reduction in control costs by saving labor and time. Herbicide absorption into the target plant largely depends on its interaction with atmosphere, soil or the soil atmosphere interface. Several environmental factors such as temperature, moisture, relative humidity and solar radiation influence a plant's physiologic status and its susceptibility to herbicides. To understand this in a better way, Alizade *et al.* (2021) conducted an experiment at Tarbiat Modares University, Iran to study the effect of different herbicides under drought stress and non drought stressed conditions. The results revealed that ED₅₀ of drought stressed weeds was greater than non drought stressed plants that is 24.4 and 15.7 g *a.i./ha* upon application of sulfosulfuron and sulfosulfuron + metsulfuron-methyl, respectively for control of *Hordeum spontaneum*. There was 13.4 and 8.1 g *a.i./ha* of ED₅₀ value was observed in 60% field condition that is drought stressed condition upon application of clodinafop-propargyl and mesosulfuron-methyl + iodosulfuron-methyl sodium, respectively for control of *Avena sterilis subsp. Ludoviciana*. Hence, from this study it was concluded that as there was less moisture affects the absorption and translocation of herbicides in weeds which ultimately leads to reduced herbicide efficacy.

Comment [BD29]: the

Comment [BD30]: and

Conclusion

Photosynthetic rate and competitive ability increases in invasive weeds under climate change, resulting in increased root growth and weed biomass, making it more difficult to control. Herbicides are important tools for weed management and offer several benefits to growers by being cost-effective and more reliable than any other methods of weed control, but the chemical properties of herbicides are as ~~much~~ sensitive to climate change as plant growth and development. Hence, adopting some of the possible practices for weed management and improving herbicide efficacy under climate change is must.

Comment [BD31]: increase

References:

Alizade, S., Keshkar, E., Mokhtassi-Bidgoli, A., Sasanfar, H. and Streibig, J. C. (2021). Effect of drought stress on herbicide performance and photosynthetic activity of *Avena sterilis subsp. ludoviciana* (winter wild oat) and *Hordeum spontaneum* (wild barley). *Weed Res.*, 61(4): 288-297.

Coetzer, E. (2001). Glufosinate efficacy, absorption and translocation in amaranthas affected by relative humidity and temperature. *Weed Sci.*, 49: 8-13.

Comment [BD32]: Add other authors name Al-Khatib K , Loughin TM

Comment [BD33]: Include issue no. (1)

Dukes, J. S., Pontius, J. and Orwig, D. (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can be predicted? *Can. J. For. Res.*, 39: 231-248.

Comment [BD34]: Write *et al.*, as there are 13 more authors

Gozde, M. and Dogan, M. N. (2015). Influence of different CO₂ levels on the growth and competition of some important weeds in wheat (*Triticum aestivum* L.). *Poljoprivreda I Sumarstvo*, 61(1): 35-38.

Comment [BD35]: Journal of agriculture and forestry?????

IPCC (1995). Climate change: A glossary by the Inter governmental panel on climate change. IPPCC, Geneva, Switzerland.

IPCC (2007). Climate change 2007- Synthesis report. Summary for Policymakers.

Jabran, K. (2016). Determination of the growth and herbicide sensitivity of some invasive Plants under different carbon dioxide, temperature and nitrogen conditions. (Ph.D. Thesis) Adnan Menderes University, Republic of Turkey. p. 90.

Comment [BD36]: Check whether it is page 90 or 90 pages

Jabran, K., Doğan, M. N. and Gozde, M. (2018). High carbon dioxide concentration and elevated temperature impact the growth of weeds but do not change the efficacy of glyphosate. *Pest Manage. Sci.*, 74(3): 766-771.

Comment [BD37]: Omit "Gozde, M" and check authors properly

Kumar, B., Rathore, M. and Singh, R. (2011). Effect of elevated CO₂ and temperature on efficacy of sulfosulfuron against *Phalaris minor*. *Indian J. Agril. Sci.*, 83(2): 176-179.

Comment [BD38]: Check the article, authors name

Kumar, B., Singh, R. and Tyagi, V. C. (2014). Weed management under the regime of climate change—Recent advances. *National training*, p.120.

Comment [BD39]: Check the paper ..Omit 'Singh R'; correct the year (2015); page: 120-125

Kumar, S. and Varshney, J. G. (2010). Gajarghas ka jaivik niyantrana: Vartman sthathi and sambhavnaie (in Hindi) [Biological control of Parthenium: current status and prospects, 157p].

Comment [BD40]: Write Kumar, S. instead of sushilkumar
Check the article again and match the year of publication and name of authors

Comment [BD41]: Arrange it chronologically in ascending order

Lee, J. S. (2011). Combined effect of elevated CO₂ and temperature on the growth and phenology of two annual C₃ and C₄ weedy species. *Agriculture, ecosystems & environment*, 140(3-4): 484-491.

Manea, A., Leishman, M. R. and Downey, P. O. (2011). Exotic C₄ grasses have increased tolerance to glyphosate under elevated carbon dioxide. *Weed Sci.*, 59(1): 28-36.

Naidu, V. S. G. R. (2015). Climate change, crop-weed balance and the future of weed management. *Indian J. Weed Sci.*, 47(3): 288–295.

Comment [BD42]: Year will be 2015 instead of 2012

Rogers, H. H., Runion, G. B., Prior, S. A., Price, A. J., Torbert, H. A. and Djerstad, D.H. (2008). Effects of elevated atmospheric CO₂ on invasive plants: Comparison of purple and yellow nutsedge (*Cyperus rotundus* L. and *Cyperus esculentus* L.), *J. Environ. Qual.*, 37: 395-400.

Comment [BD43]: Add Djerstad, D.H.

Singer, A., Travis, J. M. J., and Johst, K. (2013). Interspecific interactions affect species and community responses to climate shifts. *Oikos*, 122: 358–366.

UNFCCC (1994). [The united nations framework convention on climate change.](#)

Ziska, L. H. and Goins, E. W. (2007). Elevated atmospheric carbon dioxide and weed populations in glyphosate treated soybean. *Crop Sci.*, 46: 1354-1359.

Comment [BD44]: Check the year of publication, whether it is 2006 or 2007??

- Alizade, S., Keshtkar, E., Mokhtassi-Bidgoli, A., Sasanfar, H. and Streibig, J. C. (2021). Effect of drought stress on herbicide performance and photosynthetic activity of *Avena sterilis* subsp. *ludoviciana* (winter wild oat) and *Hordeum spontaneum* (wild barley). *Weed Res.*, 61(4): 288-297.
- Coetzer, E. (2001). Glufosinate efficacy, absorption and translocation in amaranthas affected by relative humidity and temperature. *Weed Sci.*, 49: 8-13.
- Dukes, J. S., Pontius, J. and Orwig, D. (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can be predicted? *Can. J. For. Res.*, 39: 231-248.
- Gozde, M. and Dogan, M. N. (2015). Influence of different CO₂ levels on the growth and competition of some important weeds in wheat (*Triticum aestivum* L.). *Poljoprivreda I Sumarstvo*, 61(1): 35-38.
- IPCC (1995). Climate change: A glossary by the Inter governmental panel on climate change. IPPCC, Geneva, Switzerland.
- IPCC (2007). Climate change 2007—Synthesis report, Summary for Policymakers.
- Jabran, K. (2016). Determination of the growth and herbicide sensitivity of some invasive Plants under different carbon dioxide, temperature and nitrogen conditions. (Ph.D. Thesis) Adnan Menderes University, Republic of Turkey, p. 90.
- Jabran, K., Doğan, M. N. and Gozde, M. (2018). High carbon dioxide concentration and elevated temperature impact the growth of weeds but do not change the efficacy of glyphosate. *Pest Manage. Sci.*, 74(3): 766-771.
- Kumar, B., Rathore, M. and Singh, R. (2011). Effect of elevated CO₂ and temperature on efficacy of sulfosulfuron against *Phalaris minor*. *Indian J. Agril. Sci.*, 83(2): 176-179.
- Kumar, B., Singh, R. and Tyagi, V. C. (2014). Weed management under the regime of climate change—Recent advances. *National training*, p.120.

Lee, J. S. (2011). Combined effect of elevated CO₂ and temperature on the growth and phenology of two annual C₃- and C₄-weedy species. *Agriculture, ecosystems & environment*, 140(3-4): 484-491.

Manca, A., Leishman, M. R. and Downey, P. O. (2011). Exotic C₄-grasses have increased tolerance to glyphosate under elevated carbon dioxide. *Weed Sci.*, 59(1): 28-36.

Naidu, V. S. G. R. (2012). Climate change, crop-weed balance and the future of weed management. *Indian J. Weed Sci.*, 47(3): 288-295.

Rogers, H. H., Runion, G. B., Prior, S. A., Price, A. J. and Torbert, H. A. (2008). Effects of elevated atmospheric CO₂ on invasive plants: Comparison of purple and yellow nutsedge (*Cyperus rotundus* L. and *Cyperus esculentus* L.). *J. Environ. Qual.*, 37: 395-400.

Singer, A., Travis, J. M. J., and Johst, K. (2013). Interspecific interactions affect species and community responses to climate shifts. *Oikos*, 122: 358-366.

Sushilkumar and Varshney, J. G. (2010). Gajarghas ka jaivik niyantrana: Vartman sthathi and sambhavnaie (in Hindi) [Biological control of Parthenium: current status and prospects, 157p.

UNFCCC (1994). The united nations framework convention on climate change.

Ziska, L. H. and Goins, E. W. (2007). Elevated atmospheric carbon dioxide and weed populations in glyphosate treated soybean. *Crop Sci.*, 46: 1354-1359.

Comment [BD45]: Write Kumar, S. instead of sushilkumar