Potential of Foliar Applied Thiourea in Improving Salt and High Temperature Tolerance of Bread Wheat (*Triticum aestivum*)

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Received ________________*; Accepted* ________________*; Published* ________________

Novelty statement

Thiourea has been rarely exploited for improving wheat growth under stress conditions. These results show that foliar application of thiourea to wheat was effective in substantially improving root growth at young stage while economic yield at maturity both under high temperature and salinity stresses. WE found that improved root growth with foliar-applied thiourea was a major factor in bringing about these changes.

Abstract

In this research, we investigated the possible role of foliar spray of 10 m*M* thiourea in improving the salinity tolerance threshold (EC_e) and high temperature tolerance of five wheat (*Triticum aestivum* L.) varieties at seedling, pre-anthesis and grain filling stages of growth. Data were recorded for changes in length and dry weight of shoot and root and leaf area at seedling and pre-anthesis stages, while yield and yield components were recorded at maturity. Results revealed great varietal differences in the salinity and high temperature tolerance at all growth stages. Foliar applied thiourea improved EC_e (6–11%) and high temperature tolerance (4–10%) in these varieties at different stages. Correlations of growth and yield attributes substantiated the effectiveness of foliar spray of thiourea in promoting root growth at seedling and pre-anthesis stages, and grain filling and harvest index at maturity. Among the varieties, thiourea was more effective in enhancing high temperature tolerance of the most high temperature sensitive (S-24) and EC_e of most salt sensitive (MH-97) varieties. In crux, foliar spray with thiourea has a great potential to mitigate the adverse effects of salinity and high temperature and may be recommended for field use in the areas, where moderate salinity or high temperature limit wheat production.

Keywords: Correlations; Foliar spray; Grain yield; Root growth; Stress tolerance; Wheat

Introduction

Increased soil salinity and ambient temperature are amongst the major factors affecting plant productivity. Tolerance to salinity and high temperature involve the simultaneous expression of a number of genes, leading to varied synthesis of metabolites. Both these stresses have some common adversaries on plants, such as altered morphological development, reductions in gas exchange attributes, assimilate partitioning, altered patterns of protein synthesis, changes in the activities of antioxidants and disruption of membrane functions (Zhu 2002; Sairam and Tyagi 2004; Pandey *et al.* 2011; Taiz *et al.* 2015). Salinity of soils is increasing rapidly all over the world because of irrigation of crops with low quality water, thus leading to net accumulation of ions in the root zone (Murillo-Amador *et al.* 2002; Pitman and Lauchli 2002). High temperature damages field grown crops and limits growth and yield by acting as a dehydrative force and aggravates the prevailing stress conditions (Wahid *et al.* 2007).

The plant stress tolerance can be improved with the exogenous use of stress alleviating chemicals (Wahid and Shabbir 2005; Farooq *et al.* 2009a, b). Among the stress alleviating compounds, thiourea is an important molecule with two functional groups; 'thiol' is important to oxidative stress response and 'imino' partly fulfils the N requirement. It is highly water soluble and easily absorbed in the living tissues (Wahid *et al.* 2017). Although role of thiourea in abiotic stress tolerance is scarcely investigated, available reports show that it relieves salinity induced seed dormancy in *Allenrolfea occidentalis* at lower concentration (Gul and Weber 1998). Under conditions of water stress or high temperature, external use of thiourea can increase K^+ uptake by chickpea and reduce ABA biosynthesis (Aldasoro *et al.* 1981). Foliar application of thiourea improved net photosynthesis and chlorophyll content in drought stressed clusterbean (*Cyamopsis tetragonoloba*) plants (Garg *et al.* 2006). Recently, Srivastava *et al.* (2010) have reported that thiourea treatment coordinately bioregulates different signaling and effector mechanisms and alleviates the adverse effects of high salinity in salt-treated *Brassica juncea* seeds.

Wheat (*Triticum aestivum* L.) has been ranked as tolerant to salinity with a salinity tolerance threshold (EC_e) value between 6 and 8.6 dS m^{-1} (Carter 1981; Farooq *et al.* 2009a). While being a winter crop, it is also sensitive to episodes of high temperature (Yang *et al.* 2002). In view of the changing climatic conditions mainly related to global warming, high temperature aggravates the salinity status of the field at crucial stages like germination and reproductive growth periods, leading to hampered field stand in the former case and diminished final grain yield in the latter case. We predict that foliar application of thiourea solution can enhance EC_e and high temperature tolerance of wheat. Thus, the objectives of this study were to explore the tendency of foliar-applied thiourea in improving EC_e and heat tolerance and sorting out some mechanism of thiourea action in salinity and high temperature stress tolerance of wheat at three growth stages.

Materials and Methods

Experimental details and treatments

Experimental material: Experiments were performed in the net-house of the Department of Botany, University of Agriculture, Faisalabad, Pakistan during November-April of the years 2016–2017 and 2017–2018. Seed of wheat (*Triticum aestivum* L.) varieties, Inqlab-91, MH-97, BK-2002 and SH-2002 was obtained from Wheat Breeder, Ayub Agricultural Research Institute (AARI), Faisalabad, while that of S-24 from Department of Botany. Six seeds of each variety were directly sown in glazed pots (45 cm high with 25 cm diameter from the neck and 18 cm from bottom) containing thoroughly washed sand (20 kg) and kept in the net-house. After germination, three uniform seedlings were maintained in each pot. Plants were supplemented with half-strength nutrient solution (Hoagland and Arnon 1950) throughout their growth periods.

Treatments: For the determination of salinity tolerance threshold (EC_e), wheat varieties were exposed to 0, 60, 80, 100 and 120 m*M* levels of NaCl at the rate of 20 m*M* NaCl per day separately at seedling

(20 day old plants), pre-anthesis (60 day old plants) and grain filling stages (80 day old plants). For high temperature environment, plants were shifted to open door plexiglass fitted canopies with a light transmission index of about 0.8. The canopies had 7–10°C higher temperature as compared to ambient (Fig. 1). Average photosynthetically active radiations on the leaf surface ranged between 855 to 975 µmol m^{-2} s^{-1} (measured with Infra-Red Gas Analyzer, LCA-4, Analytical Development Company, Hoddesdon, England) and relative humidity 55–60 and 35–40% during winter and summer months, respectively. Pots were protected from rainfall by covering with transparent plastic sheet. Plants from all the treatments were divided into three groups, which were foliar sprayed with none (group-I), sprayed with distilled water (group-II) and sprayed with 10 m*M* thiourea solution (group-III) were sprayed with a sprayer. Effective concentration, 10 m*M*, of thiourea for foliar spray was pre-optimized after conducting series of experiments (data not shown).

Plant harvesting

The plants were harvested 15 days after applying treatment at each stage. At seedling stage, the determinations were made for length and dry weight of shoot and root and leaf area per plant. At pre-anthesis stage, in addition to measurements made at seedling stage, flag leaf area was also measured. At both these stages total and flag leaf areas were determined of intact plants as maximum leaf length and maximum leaf width × 0.68 (correction factor). Dry weight was determined after drying the harvested plants at 70°C for seven days. The plants receiving high temperature and salinity stresses at grain filling stage were harvested at full maturity to determine grain yield and yield components. The seeds were extracted from the spikes to determined grain yield per plant.

Assessment of stress tolerance

Salinity tolerance threshold (EC_e) values of wheat varieties were determined with the equation of Maas and Hoffman (1977):

$$Yr = 100 - B\,(EC_e - A)$$

Where Yr is the relative yield; slope B represents the decrease in yield and threshold A is the lowest salinity (EC_e in dS m^{-1}), which significantly reduces yield. Net change in the EC_e due to foliar thiourea application was calculated in percentage based on the individual characters, as well as average for each variety computed.

For determination of any change in the high temperature tolerance with or without thiourea application, the values were computed as percent change in individual growth and yield attributes over respective controls and averages calculated for each variety. Net change was computed as difference of thiourea-sprayed versus non-sprayed treatments.

Statistical analysis

In the absence of any striking differences in the plants from group-I and group-II (not sprayed and sprayed with water, respectively), the comparison and derivations were made between the group-II and group-III plants (foliar sprayed with water and 10 m*M* thiourea solution). Design of the experiments was completely randomized with three replications. The data for both the years was averaged to determine comparative responses of varieties in terms of changes in EC_e and high temperature tolerance separately with or without thiourea spray. Data were statistically analyzed using COSTAT computer software (COHORT, Monterey, California).

Results

Changes in stress tolerance with thiourea

Salinity tolerance: Wheat varieties indicated significant differences for EC_e and improvement in it after foliar spray with thiourea at seedling ($P<0.05$), pre-anthesis ($P<0.01$) and maturity ($P<0.05$) stages. At seedling stage, S-24 showed EC_e of 8.55, followed by BK-2002 and SH-2002 (7.76 and 7.73, respectively), whilst Inqlab-91 (7.10) and MH-97 (6.85) were the most sensitive. Although enhanced in all the varieties with thiourea, maximum improvement in EC_e was recorded in SH-2002, BK-2002, MH-97 (9.67, 9.60 and 9.09%, respectively) followed by Inqlab-91 (8.45%), whereas S-24 (7.42%) displayed the minimum EC_e (Table 1).

At pre-anthesis stage, S-24 indicated the greatest average EC_e (9.66 dS m^{-1}) followed by SH-2002, BK-2002 and Inqlab-91, while MH-97 faired very poorly, displaying EC_e of 6.63 dS m^{-1}. Foliar applied thiourea although improved EC_e in all the varieties, BK-2002 excelled the other varieties by showing an enhancement in EC_e of 11.16%, followed by MH-97 and Inqlab-2002 (Table 1). At maturity stage, EC_e assessed on the basis of grain yield and yield components revealed that except MH-97, showing the lowest EC_e, all the varieties indicated improved EC_e but did not differ ($P>0.05$) from each other. Foliar spray with thiourea improved the EC_e of all the varieties, and the maximum enhancement was noted in SH-2002 and MH-97, followed by S-24 and BK-2002, while Inqlab-91 was at the bottom (Table 1).

High temperature tolerance: All the varieties indicated a decline in growth and yield attributes at prevailing high temperature, but foliar applied thiourea significantly ($P<0.01$) improved the high temperature tolerance at seedling, pre-anthesis and maturity stages. A comparison of varieties showed that S-24 and BK-2002 indicated greatest decline in the growth attributes followed by SH-2002, MH-97 and Inqlab-91. Foliar application of 10 m*M* thiourea improved growth of all the varieties under high temperature and brought about net improvement in the order of BK-2002 > S-24 > MH-97 > SH-2002 > Inqlab-91 (Table 2).

At pre-anthesis stage, the wheat varieties indicated substantial reduction in high temperature tolerance over respective controls and S-24 was the most affected showing an average decline of ~22%, while MH-97 was minimally influenced (~12%). Foliar application of thiourea curtailed the reductions in growth attributes and as a result the varieties indicating average net improvement were in the rank: S-24 (9.48) > MH-97 (6.53%) > BK-2002 (6.50%) > BK-2004 (6.38%) > SH-2002 (5.12%), respectively (Table 2). Towards maturity, data recorded for changes in grain yield and yield components due to high temperature revealed that S-24 underwent a greatest reduction (22.86%) followed by BK-2002 (17.31%), Inqlab-91 (16.72%), SH-2002 (16.24%), while MH-97 manifested a lowest reduction (10.47%). Foliar spray with thiourea produced a net improvement in high temperature tolerance of these varieties in the orders: Inqlab-91 > S-24 > SH-2002 > BK-2002 > MH-97, respectively (Table 2).

Discussion

Although some reports show improvement in plant growth by exogenous use of thiourea (Burman *et al.* 2004; Garg *et al.* 2006), none is available on the enhancement in the EC_e and high temperature tolerance in thiourea-sprayed plants. In this study, foliar use of thiourea improved the EC_e and high temperature tolerance at three growth stages, but the extent of improvement was differential for the stress treatments as well as varieties at three growth stages. Foliar applied thiourea was highly more effective in improving the EC_e of salt sensitive varieties (MH-97, BK-2002 and SH-2002) at seedling, pre-anthesis and maturity (Table 1). Likewise, S-24 being less tolerant of high temperature indicated substantially improved growth and yield after foliar spray with thiourea at all phenological stages (Table 2).

Results of this study indicated that improved EC_e and high temperature tolerance of thiourea-applied plants was primarily linked to improved growth and yield parameters (see Materials and methods section), on the basis of which the data presented in Table 1 and 2 were derived. This implied that the primary action of thiourea is to improve net assimilation efficiency of plant by alleviating salinity and high temperature damage to photosynthetic area, which is crucial for stress tolerance (James *et al.* 2002; Wahid 2007; Huang *et al.* 2019). Improved leaf area, particularly flag leaf area with thiourea application proved important for providing greater surface area for the production and partitioning of photoassimilates towards vegetative and reproductive growth (Gibberd *et al.* 2002). It is noteworthy that such improvements were better discernible in case of sensitive varieties, irrespective of the prevailing stress condition, which definitely signifies the tendency of foliar use of thiourea in improving stress tolerance of wheat.

Both salinity and high temperature have a common facet of oxidative damage (Desikan *et al.* 2005; Wahid *et al.* 2007). Looking at the structure of thiourea, both 'imino' and 'thiol' functional groups have great implications in abiotic stress tolerance. With foliar spray imino group provides a ready source of nitrogen and thiol has a great role in alleviating oxidative stress damage on the physiologically more important mesophyll tissue. It was evident from the results that foliar applied thiourea was effective in improving salt- (6–11%) and high temperature tolerance (4–10%) of wheat varieties due to its abiotic stress-mitigating properties. Prolific root system is important to stress tolerance and improved final yield (Flowers 2004; Farooq *et al.* 2009b). In line with this, a pronounced increase in root growth of salt- and high temperature-sensitive varieties was directly associated to grain yield, which is an important manifestation of thiourea action in improving wheat growth of more sensitive varieties at various growth stages. Thus, in view of being water soluble, readily absorbable in the tissues and ability to ameliorate stress effects, field use of thiourea is beneficial in achieving better wheat yield from relatively warm and saline areas.

Conclusion

Although with substantial varietal difference, thiourea can be effectively used to produce salinity and high temperature tolerance in wheat. The possible mechanism may the reduced activity of ions in the growing medium. Further studies are needed to find the possible mechanism(s) of the growth improvement as noted in the present study.

Acknowledgements

The first author acknowledges the financial grant from University of Agriculture, Faisalabad, Pakistan

Author contributions

FA and AW planned the experiments, MF and SMAB interpreted the results, FA, AW and MF made the write up and FJ statistically analyzed the data and made illustrations

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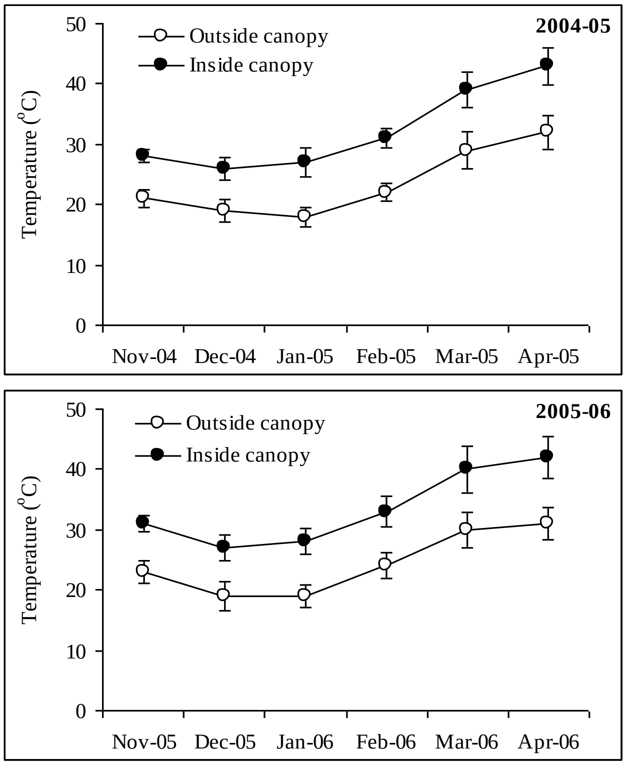

Fig. 1: Maximum temperature inside and outside of the canopy (recorded at 12 noon) during crop growth months of 2004–2005 and 2005–2006

Table 1: Salinity tolerance threshold (EC_e) of wheat varieties, change in it after foliar spray with thiourea and net improvement in EC_e at various growth stages

Growth stage	Varieties	Salinity	Salinity and thiourea spray	Net improvement (%)
Seedling	S-24	8.55±0.29a	9.27±0.82a	7.42±1.42b
	Inqlab-91	7.10±1.03b	7.74±0.84b	8.45±0.91ab
	MH-97	6.85±0.65b	7.52±0.51b	9.09±1.31a
	BK-2002	7.76±0.99ab	8.60±1.11ab	9.60±1.67a
	SH-2002	7.73±0.53ab	8.55±0.12ab	9.67±1.61a
Pre-anthesis	S-24	9.66±0.60a	10.43±0.70a	7.32±1.15c
	Inqlab-91	7.99±0.70b	8.82±0.83b	9.38±0.95b
	MH-97	6.63±1.21c	7.41±1.08c	10.88±1.13ab
	BK-2002	8.18±0.54b	9.21±0.68b	11.16±1.18a
	SH-2002	8.38±0.59b	8.97±0.55b	7.61±1.14c
Maturity	S-24	9.28±0.70a	10.11±0.65a	8.32±0.74b
	Inqlab-91	8.90±0.76a	9.46±0.67ab	5.89±0.72c
	MH-97	7.84±0.83b	8.70±0.93b	9.87±0.94a
	BK-2002	8.92±0.52a	9.71±0.31a	8.20±0.72b
	SH-2002	9.18±0.32a	10.33±0.68a	10.82±0.99a

Mean ± standard deviation. Values sharing same letters differ non-significantly ($P>0.05$)

Table 2: Changes in high temperature tolerance of wheat varieties, changes and net improvement in it after foliar spray with thiourea at various growth stages

Growth stage	Varieties	High temperature	High temperature and thiourea spray	Net improvement (%)
Seedling	S-24	14.95±1.98a	9.03±1.49a	5.93±0.49a
	Inqlab-91	10.06±0.84b	5.72±1.27b	4.33±0.68b
	MH-97	11.01±1.31b	5.79±0.57b	5.22±0.98ab
	BK-2002	14.61±1.67a	8.42±0.66a	6.19±0.79a
	SH-2002	11.94±1.61b	7.48±0.48a	4.47±0.97b
Pre-anthesis	S-24	21.78±1.95a	12.30±2.17a	9.48±1.39a
	Inqlab-91	15.20±1.09b	8.82±1.27c	6.38±0.91bc
	MH-97	11.61±1.78c	5.08±0.56c	6.53±1.04b
	BK-2002	16.27±1.96b	9.77±1.14bc	6.50±1.06b
	SH-2002	16.95±1.61b	11.83±1.18ab	5.12±0.81c
Maturity	S-24	22.86±2.28a	15.12±1.03a	7.74±0.26ab
	Inqlab-91	16.72±1.15b	8.32±0.32d	8.41±0.70a
	MH-97	10.47±0.68c	4.69±0.71e	5.78±0.93d
	BK-2002	17.31±2.40b	11.22±1.31b	6.09±0.60c
	SH-2002	16.24±2.20b	9.63±1.03c	6.61±0.69b

Mean ± standard deviation. Values with same letter differ non-significantly (P>0.05).

Standard measurement units and their abbreviations

Full name	**Symbol**
Barrel	bbl
Base	b
Base pair	bp
Byte	B
Centimeter	cm
Degree centigrade	^{o}C
Degree Fahrenheit	^{o}F
Einstein	*E*
Giga	G
Gram	g
Gravity	*g*
Hectare	ha
Joule	J
Kilogram	kg
Kilowatt	kW
Kilowatt-hour	kWh
Liter	L
Megabyte	MB
Meter	m
Mega	M
Metric ton	MT
Microgram	µg
Microliter	µL
Micrometer	µm
Milligram	mg
Milliliter	mL
Millimeter	mm
Millimole	m*M*
Mole	*M*
Revolutions per minute	rpm
Square	sq.
Volt	V
Watt	W

Standard Countries abbreviations

Country full name	**Abbreviation**
Africa, African	*Afr.*
America, American	*Amer.*
Australia	*Aust.*
Austria	*Aus.*
Bangladesh	*Bang.*
Belgium	*Belg.*
Brazil	*Braz.*
British, Britain	*Brit.*
Bulgaria	*Bulg.*
Canadian	*Can.*
Chili, Chilean	*Chil.*
China, Chinese	*Chin.*
Egyptian	*Egypt.*
Emirates	*Emir.*
European	*Eur.*
India, India	*Ind.*
Indonesia, Indonesian	*Indo.*
Iranian	*Iran.*
Israel	*Isr.*
Italian	*Ital.*
Japan	*Jpn.*
Korea, Korean	*Kor.*
Malaysian	*Malays.*
New Zealand	*N.Z.*
Nigeria, Nigerian	*Nig.*
Pakistan	*Pak.*
Philippines	*Phil.*
South African	*S. Afr.*
Scandanavian	*Scand.*
Spanish	*Span.*
Sweden	*Swed.*
Turkey, Turkish	*Turk.*

Some common abbreviations in journals names

Full name	Abbreviation
Academic, Academia	Acad.
Addiction	Addict.
Addition	Addit.
Advances, Advancement	Adv.
Agriculture, Agricultural	Agric.
Agronomy, Agronomic	Agron.
Alternative, Alternate	Antern.
Analytical, Analysis	Anal.
Anatomy	Anat.
Annal(s)	Ann.
Annual	Annu.
Aquatculture	Aqualt.
Aquatic	Aquat.
Archive(s)	Arch.
Association(s)	Assoc.
Bacteriological	Bacteriol.
Bacterium, Bacteria	Bacter.
Behavior, Behave	Behav.
Biology, Biological, Biologia	Biol.
Bioremediation	Bioremed.
Biotechnology	Biotechnol.
Botany, Botanical, Botanica	Bot.
Breeding, Breeder	Breed.
Cellular	Cell.
Chemistry, Chemical	Chem.
Chromatograph(y), Chromatographer	Chromatogr.
Clinical	Clin.
Communication(s)	Commun.
Computer(s), Computational	Comput.
Contamination, Contaminant	Contam.
Critical	Crit.
Culture	Cult.
Current	Curr.
Cycle, Cycling	Cycl.
Development, Developmental	Dev.
Diagnostic	Diagn.
Disease	Dis.
Diverse, Diversity	Divers.
Dynamic	Dynam.
Ecology , Ecological	Ecol.
Economic, Economical	Econ.
Electric, Electrical	Electr.
Electronic	Electron.
Engineering, Engineer	Eng.
Entomology, Entomological	Entomol.
Environment, Environmental	Environ.
Epidemiology	Epidemiol.
Experimental	Exp.
Faculty	Fac.
Forestry, Forest	For.
Function(s), Functional	Funct.
General	Gen.
Genetics, Genetica	Genet.
Geology	Geol.
Hazardous	Haz.
Horticulture, Horticultural, Hirticulturae	Hortic.
Immunology, Immunological	Immun.
Information, Informational	Inform.
Instrument(s)	Instrum.
Integrative	Interg.
Interaction(s), Interactive	Interact.
International	Intl.
Journal(s)	J.
Letter(s)	Lett.
Liquid	Liq.
Magnetic, Magnet	Magn.
Management	Manage.
Marine, Marina	Mar.
Material(s)	Mater.
Mathematics, Mathematical	Math.
Mechanic, Mechanical, Mechanism	Mech.
Medical, Medicine, Medica	Med.
Metabolism, Metabolic	Metab.
Microbiology	Microbiol.
Modern	Mod.
Molecule, Molecular	Mol.
Monitor, Monitoring	Monit.
Morphology, Morphological	Morph.
Nature, Natural	Nat.
National	Natl.
Nutrition, Nutritional, Nutrient(s)	Nutr.
Oecologia	Oecol.
Operation, Operational	Oper.
Opinion	Opin.
Optic, Optical	Opt.
Organ, Organic	Org.
Parasitology, Parasitological	Parasotol.
Pathology, Pathological	Pathol.
Pediatrics	Pediatr.
Pharmacology	Pharmacol.
Pharmacy, Pharmaceutical	Pharm.
Philosophy, Philosophical	Phil.
Phycology, Phycological	Phycol.
Physics, Physical	Phys.
Physiology, Physiological, Physiologia	Physiol.
Phytology, Phytologist(s)	Phytol.
Plantarum	Plantarum
Pollution	Pollut.
Polymer	Polym.
Practice, Practical, Practitioner	Prac.
Production, productive	Prod.
Program, Progress, Progressive	Prog.
Quality, Qualitative	Qual.
Quantity, Quantitative	Quant.

Radiation	Radiat.	Surgery, Surgical	Surg.
Registration	Reg.	Survey(s)	Surv.
Regulation, Regulator(s)	Regul.	Sustainable	Sustain.
Rehabilitation	Rehabil.	System(s), Systematic(s)	Syst.
Reproduction, Reproductive	Reprod.	Technique, Technical,	Tech.
Resource(s)	Resour.	Technological	Technol.
Revegetation	Reveg.	Theoretical, Theory, Theorem	Theor.
Review(s)	Rev.	Therapy, Therapeutical	Ther.
Safe, Safety	Saf.	Tillage	Till.
Science, Scientia, Scientific	Sci.	Toxic	Tox.
Sensing, Sensor(s)	Sens.	Toxicology, Toxicological	Toxicol.
Service(s)	Serv.	Transaction(s)	Trans.
Signaling	Signal.	Tropical, Tropics	Trop.
Sinica	Sin.	Vegatable(s), Vegatale	Veg.
Society	Soc.	Veterinary, Veterinus,	Vet.
Software	Softw.	Virological	Virol.
Statistical, Statistics, Statistician	Stat.	Virus, Viral	Vir.
Structure, Structural	Struct.	Weekly	Wkly.
Studies	Stud.	Wetland	Wetl.
Surface	Surf.	Zoology, Zoological, Zoologica	Zool.
Surgery, Surgical	Surg.		

Journal names NOT to be abbreviated when given as SINGLE WORD

Addiction
Aerobiologia
Age
Agribusiness
Agrochimica
Aids
Alcohol
Allergologie
Allergy
Ambio
Animal
Anthropologist
Antibiotiques
Apoptosis
Appetite
Aquaculture
Atherosclerosis
Atmosfera
Autophagy
Bioanalysis
Biochemistry
Biochimie
Biocontrol
Biodegradatiom
Bioelectrochemistry
Bioelectromagnetics
Bioessays
Bioethics
Biofabrication
Biofactors
Biofouling
Biofutur
Biogeochemistry
Biogeosciences
Biogerontology
Bioinformatics
Biointerphases
Biologia
Biologicals
Biomacromolecules
Biomarkers
Biomaterials
Biomedica
Biometals
Biometrics
Biometrika
Biomicrofluidics
Biopolymers
Bioresources
Biorheology
Bioscience
Biostatistics
Biosystems
Biotechniques
Biotropica
Blood
Bone
Brain
Breast
Bryologist
Burns
Caryologia
Cell
Chemosphere
Chest
Chimia
Chromatographia
Chromosoma
Circulation
Clinics
Computer
Computing
Cornea
Cortex
Cryobiology
Dendrobiology
Dendrochronologia
Dermatitis
Development
Diabetes
Diabetologe
Diabetologia
Digestion
Drugs
Ecotoxicology
Ecotropica
Environment
Environmetrics
Epidemiology

Epigenetics-us
Epigenomics-uk
Epilepsia
Euphytica
Farmacia
Fisheries
Flora
Forestry
Fruits
Genetica
Genetics
Genome
Genomics
Geobiology
Glycobiology
Grana
Heart
Helicobacter
Helminthologia
Hematology
Hemoglobin
Hereditas
Heredity
Hortscience
Hydrobiologia
Hypertension
Iforest
Immunity
Immunobiology
Immunogenetics
Immunology
Infection
Injury
Interciencia
Intervirology
Kardiologiya
Labmedicine
Maydica
Mealthmed
Medicine
Metabolism
Metabolomics
Molecules
Mutagenesis
Mycologia
Mycopathologia
Mycorrhiza
Mycoscience
Mycoses
Mycotaxon
Nature
Nephrology
Neuroinformatics
Neurologist
Neurology
Neuromodulation
Neuropathology
Neuropediatrics
Neuropeptides
Neuropharmacology
Nutrients
nutrition
Oceanologia
Oecologia
Oncogene
Palaeontology
Palynology
Pancreas
Pancreatology
Pathobiology
Pathologe
Pathology
Patient
Pediatrics
Pedologia
Pedosphere
Pharmacogenomics
Pharmacology
Photosynthetica
Phycologia
Physiology
Physiotherapy
Phytochemistry
Phytomedicine
Phytoparasitica
Phytopathology
Planta
Platelets
Primates
Prostate
Proteins
Proteomics
Protist
Protoplasma
Protoplasma
Rehabilitation
Reproduction
Respiration
Respirology
Science
Scienceasia
Scientist
Statistics
Steroids
Stress
Symbiosis
Theriogenology
Transfusion
Tuberculosis
Ultramicroscopy
Urologe
Urology
Vaccine
Virologie
Virology
Wetlands
Yeast
Zoology
Zoomorphology
Zoosystema
Zootaxa
Zuchtungskunde
Zuckerindustrie
Zygote