glyphosate
N-(phosphonomethyl)glycine

NOMENCLATURE
Common name: glyphosate (ANSI, BSI, ISO, WSSA)
Other name(s): ICIA2024; MONO0573;
SC-0224; 2-(phosphonomethylamino)acetic
acid; carboxymethyl-aminomethylphosphonic
acid; sulfosate = trimethylsulfonium
carboxymethylaminomethyl-phosphonate (IUPAC)
Trade name(s): ACCORD® CONCENTRATE;
ACCORD® XRT; AQUAMASTER®; AQUANEAT®;
BACKDRAFT®; CAMPAIGN®; DUPLIKATOR™ 5.5
PLUS; DURANGO™; EAGLE; EXTREME®; FALLOW
MASTER®; FALLOW STAR®; FIELD MASTER®;
FORZA™; GLY-FO; GLYFOS® AQUATIC; GLYFOS®
PRO; GLYFOS® X-TRA; GLIFOSATO ESTRELLA;
GLYPHOS XTRA®; DUPONT GLYPHOSATE
VMF; GLYPHOSATE ORIGINAL; GLYPHOGAN™;
GLYPHOMAX®, GLYPHOMAX PLUS®, GLYPRO®;
GLYPRO PLUS®; GLYPHOSATE®; GLY STAR;
HONCHO®; HONCHO® PLUS; IMITATOR® PLUS;
LANDMASTER® BW; LANDMASTER® II; MIRAGE®;
PIN-UP; POLADO L; QUIKPRO®; RANGER
PRO™; RATTLER®; RATTLER PLUS®; RAZOR®;
READY MASTER AT®; RODEO®; ROUNDP®;
ROUNDP® ORIGINAL; ROUNDP® ORIGINAL RT;
ROUNDP® PRO CONCENTRATE; ROUNDP®
CUSTOM; ROUNDP® PRO DRY; ROUNDP®
ULTRA; ROUNDP® ULTRA RT; ROUNDP®
ULTRADRY; ROUNDP® ULTRAMAX; ROUNDP®
ULTRAMAX II; ROUNDP® D-PAK; ROUNDP®
WEATHERMAX; RT 3™; RT MASTER II;
SILHOUETTE®; STAPLE® PLUS; TOUCHDOWN®;
TOUCHDOWN® PRO; WEEDOFF
Chemical family: organophosphorus

CHEMICAL AND PHYSICAL PROPERTIES
Chemical structure
glyphosate acid

\[
\begin{align*}
\text{HO-C-CH}_2\text{NH-CH}_2\text{P-OH} & \quad \text{OH} \\
\end{align*}
\]

glyphosate isopropylamine salt

\[
\begin{align*}
\text{HO-C-CH}_2\text{NH-CH}_2\text{P-O-CH}_3 & \quad \text{NH}_3\text{CH}
\end{align*}
\]

glyphosate trimethylsulfonium (trimesium) salt

\[
\begin{align*}
\text{HO-C-CH}_2\text{NH-CH}_2\text{P-O-CH}_3 & \quad \text{S-CH}_3
\end{align*}
\]

CAS # acid: 1071-83-6
Isopropylamine salt: 40465-66-5
Trimesium salt: 81591-81-3
Sesquisodium salt: 70393-85-0
Ammonium salt: 40465-66-5

glyphosate sesquisodium salt (2:3)

\[
\begin{align*}
\text{Na} & \quad \text{O-C-CH}_2\text{NH-CH}_2\text{P-O-Na} \\
\end{align*}
\]

glyphosate ammonium salt

\[
\begin{align*}
\text{HO-C-CH}_2\text{NH-CH}_2\text{P-O-NH}_3 & \quad \text{OH} \\
\end{align*}
\]

Molecular formula: Acid \(C_6H_8NO_3P\); isopropylamine
(IPA) salt \(C_6H_{16}N_2O_6P\); trimethylsulfonium (TMS) salt
\(C_6H_{12}NO_3PS\)

Molecular weight: Acid 169.07 g/mole; IPA salt 228.19 g/mole; TMS salt 245.23 g/mole

Description: Acid white solid, odorless; TMS salt
Clear amber to yellow liquid; and slight sulfur odor as
the 70% aqueous technical (dry pure glyphosate TMS
salt is strongly hygroscopic and difficult to maintain;
thus, a 70% aqueous solution is used as the technical
grade material)

Density: Acid 1.74 g/mL; 70% Aqueous TMS salt
1.23-1.25 g/mL (20 C)

Melting point: 200 C (with decomposition)

Boiling point: Acid 69 C; 70% Aqueous TMS salt 109
(2.13 x 10⁴ Pa)

Vapor pressure: Acid 2.45 x 10⁻³ Pa (45 C); 70 %
Aqueous TMS salt 3.99 x 10⁻⁶ Pa (25 C)

Stability: Acid stable for 32 d (25 C) and pH 5, 7, or
9; 70% Aqueous TMS salt stable for 32 d (25 C) and
pH 7 or 9

Solubility:

Acid

water 15,700 mg/L (pH 7, 25 C); 11,600 mg/L (pH
2.5, 25 C)

Isopropylamine salt

water 125,000 mg/L (pH 7, 25 C) (estimated) (ref.
10); 786,000 mg/L (pH 4.06, 25 C)

Trimethylsulfonium salt

water 4,300,000 mg/L (pH 7, 25 C)

\[pK_a: \text{ Acid 2.6, 5.6, and 10.3 (Acts as a weak acid)}\]

K_{ow}: 0.0006-0.0017

HERBICIDAL USE
Glyphosate is non-selective, foliar-applied, and

HERBICIDAL USE
Glyphosate is non-selective, foliar-applied, and
can be used as follows; preplant or PRE at 0.21-
2.24 kg ae/ha (ae/A) to control emerged weeds at
planting in certain annual crops planted using no till
Enolpyruvyl Shikimate-3-Phosphate (EPSP) Synthase Inhibitors

Methods: POST at 0.84-4.2 kg ae/ha or at 0.5-5% v/v of a 360 g/L product in a spray-to-wet application for general vegetation control in many noncrop areas such as industrial sites; directed POST or for site preparation at up to 4.2 kg ae/ha in ornamentals and Christmas trees; directed POST at 0.84-4.2 kg ae/ha in tree and vine crops; preharvest at 0.84-4.2 kg ae/ha in cotton; preharvest at 0.21-0.84 kg ae/ha in wheat; POST at 0.16 kg ae/ha in bahiagrass and Kentucky bluegrass; POST at 0.16-0.42 kg ae/ha in bermudagrass and POST at 0.21 kg ae/ha in fescues, orchardgrass, and quackgrass for suppression of these perennial grasses on orchard floors; and for control of woody vegetation by injection or frill treatment or by treating cut stumps. Glyphosate can be applied with a conventional sprayer, or with recirculating sprayers, shielded applicators, and wiper applicators. It controls virtually all annual and perennial weeds, but generally is most phytotoxic to annual grasses. A non-ion surfactant is required for maximum efficacy, although certain formulated products already contain surfactant. In addition, selected formulations can be used POST in genetically modified crops tolerant to glyphosate (see mechanism of resistance section) such as soybean, corn, cotton, canola.

Use Precautions
Fire hazard: All aqueous products (ROUNDUP, RODEO, etc.) are non-flammable; flash point is >93 C.
Corrosiveness: Corrosive to iron and galvanized steel; do not hold spray mixture in galvanized or unlined steel tanks (except stainless) for extended periods.
Storage stability: All products containing only glyphosate isopropylamine salt are stable at <60 C; they freeze at -29 C but can be used upon thawing. Package mixtures may have different characteristics.
Cleaning glassware/spray equipment: Clean glassware with water. Flush sprayer parts with several changes of water.
Emergency exposure: Glyphosate is a potential irritant. No specific antidote is available. Flush eyes with water for at least 15 min. If ingested, immediately dilute by swallowing milk or water.
Incompatibilities: Tank mixing with residual herbicides such as substituted ureas and triazines or with POST herbicides such as paraquat, dalapon, MSMA, phenoxy, or other auxin type herbicides may reduce glyphosate efficacy.

Behavior in Plants
Mechanism of action: Inhibits enolpyruvyl shikimate-3-phosphate (EPSP) synthase (more details on page 13)
Symptomology: Growth is inhibited soon after application followed by general foliar chlorosis and necrosis within 4-7 d for highly susceptible grasses and within 10-20 d for less susceptible species. Chlorosis may appear first and be most pronounced in immature leaves and growing points. Foliage sometimes turns reddish-purple in certain species. Regrowth of treated perennial and woody species often appears deformed with whitish markings or striations; multiple shoots (sometimes called a witch’s blemish) may develop at the nodes.
Absorption: Moderately absorbed across the cuticle when POST applied (3, 13). The isopropylamine salt of glyphosate is more readily absorbed than is glyphosate acid, and surfactant and ammonium sulfate further increase absorption of the isopropylamine salt (12). Glyphosate transport across the plasmalemma is slower than most herbicides (especially non-polar herbicides) (9), probably because of its negative charge at physiological pH. A phosphate transporter may contribute to glyphosate movement across the plasmalemma (5).
Translocation: Primarily translocated in the symplast with accumulation in underground tissues, immature leaves, and meristems (14). Apoplastic translocation has been observed in tall morningglory (6) and quackgrass (10), but most results suggest little to no apoplastic movement. Glyphosate may interfere with its own translocation from treated leaves by interfering with carbon partitioning and metabolism (8).
Metabolism in plants: Not appreciably metabolized when applied at phytotoxic rates. Glyphosate is slowly metabolized to amino methylphosphonic acid (AMPA) (4, 15).
Non-herbicidal biological properties: Sublethal rates inhibit seedhead emergence and suppress vegetative growth of most perennial grasses.
Mechanism of resistance in weeds: Lolium rigidum in S. Africa and Australia; Conyza canadensis in U.S. from altered enzyme.
Engineered tolerance in crops: Available in several species, including tobacco, tomato, petunia, corn, chicory, cotton, canola, carrot. Corydalis, and certain bacteria species.

Behavior in Soil
Sorption: Rapidly and tightly absorbed to soil. OM, clay, silt, or sand content and soil pH have minimal effect on adsorption. Glyphosate adsorption correlates with the amount of vacant phosphate sorption sites and may occur through binding of the phosphonic acid moiety. High levels of metallic cations in clay soils increase the amount of glyphosate adsorbed. Strong adsorption to soils is evidenced in part by low phytotoxicity with soil applications. Crops can be seeded or transplanted immediately into treated areas.

Kd: Average is 24,000 mL/g (estimated) (16)
Kp: 324-600 mL/g for a silty clay loam and a loamy sand
Transformation:
Photodegradation: Negligible losses
Other degradation: Degraded microbially in soil and water. Decomposition rates vary with soil and microbial population. From 10 to 70% of glyphosate may be transformed to CO₂ over a growing season or less. Non-microbial degradation rates are negligible.

Persistence: Glyphosate has moderate persistence with a typical field half-life of 47 d (16). All crops can be planted immediately after application due to strong adsorption to soil.

Lab experiments: Half-life typically is <25 d

Mobility: Low mobility on most soils in field and lab studies because of strong adsorption to soil; low potential for movement in runoff in field and lab studies

Volatilization: Negligible losses

TOXICOLOGICAL PROPERTIES

Toxicity tests were conducted with technical grade glyphosate acid unless otherwise indicated.

Acute toxicity:
Oral LD₅₀ rat, 5600 mg/kg; Dermal LD₅₀ rabbit, >5000 mg/kg; 4-h inhalation LC₅₀, NA; Skin irritation, none; Skin sensitization guinea pig, no; Eye irritation rabbit, slight

Glyphosate isopropylamine salt technical: Oral LD₅₀ rat, >5000 mg/kg; Dermal LD₅₀ rabbit, >5000 mg/kg; Skin irritation rabbit, none; Skin sensitization guinea pig, no; Eye irritation rabbit, slight

Glyphosate trimethylsulfonium salt technical: Oral LD₅₀ male rat, 748 mg/kg; female Glyphosate at, 755 mg/kg; Dermal LD₅₀ rabbit, >2000 mg/kg; 4-h inhalation LC₅₀, >5.18 mg/L; Skin irritation rabbit, mild; Skin sensitization guinea pig, mild; Eye irritation rabbit, mild

ROUNDUP: Oral LD₅₀ rat, >5000 mg/kg; Dermal LD₅₀ rabbit, >5000 mg/kg; 4-h inhalation LC₅₀ rat, 3.2 mg/L; Skin irritation rabbit, none; Skin sensitization guinea pig, no; Eye irritation rabbit, moderate

LANDMASTER BW: Oral LD₅₀ rat, 3860 mg/kg; Dermal LD₅₀ rabbit, 6366 mg/kg; Skin irritation rabbit, moderate; Eye irritation rabbit, severe

Subchronic toxicity:
90-d dietary, mouse: NOEL 2300 mg/kg/d (10,000 mg/kg); decreased weight gains at 50,000 mg/kg
90-d dietary, rat: NOEL >1400 mg/kg/d (20,000 mg/kg)

21-d dermal, rabbit: Systemic NOEL >5000 mg/kg/d; slight irritation at site of application at 5000 mg/kg/d

Chronic toxicity:
24-mo dietary, mouse: Oncogenic NOEL 4500 mg/kg/d (30,000 mg/kg); slightly lower body weight gains and several microscopic liver changes at 4500 mg/kg/d; not carcinogenic

24-mo dietary rat: NOEL 400 mg/kg/d (8000 mg/kg) carcinogenic; reduced body weight gains in females and eye changes at 1000 mg/kg/d (20,000 mg/kg)

12-mo dietary, dog: NOEL 500 mg/kg/d; no effects

Teratogenicity:
Rat: NOEL 1000 mg/kg/d; maternal and fetal mortality at 3500 mg/kg/d; not teratogenic

Rabbit: NOEL maternal 175 mg/kg/d; fetal >350 mg/kg/d; maternal toxicity at 350 mg/kg/d; no fetal toxicity

Reproduction:
Rat: NOEL ~700 mg/kg/d (10,000 mg/kg); not reproductive toxin; decreased adult and pup body weight gains and possible changes in litter size at ~2100 mg/kg/d (30,000 mg/kg)

Mutagenicity:
Gene mutation: Ames test, negative; E. coli, negative; B. subtilis rec+ and rec-, negative; CHO/point mutation, negative

Structural chromosome aberration: Mouse dominant lethal, negative; Rat bone marrow/cell clastogenesis, negative

DNA damage/repair: Rat primary culture/DNA repair, negative

Wildlife:
Bobwhite quail oral LD₅₀ >4640 mg/kg; 8-d dietary LC₅₀ >4640 mg/kg; Mallard duck 8-d dietary LC₅₀, 4640 mg/kg; Honey bee, oral LD₅₀ >100 μg/bee; topical LD₅₀ >100 μg/bee; Daphnia 48-h LC₅₀, 780 mg/L; Bluegill sunfish 96-h LC₅₀, 120 mg/L; Harlequin fish 96-h LC₅₀, 168 mg/L; Rainbow trout 96-h LC₅₀, 86 mg/L; Atlantic oyster 96-h LC₅₀, >10 mg/L; Fiddler crab 96-h LC₅₀, mg/L; Shrimp 96-h LC₅₀, 281 mg/L

Glyphosate trimethylsulfonium salt technical:
Bobwhite quail 8-d dietary LC₅₀ >5000 mg/kg; Mallard duck oral LD₅₀ 950 mg/kg; 8-d dietary LC₅₀ >5000 mg/kg; Honey bee topical LD₅₀ >62.1 μg/bee; Daphnia 48-h LC₅₀ 71 mg/L; Bluegill sunfish 96-h LC₅₀ 3500 mg/L; Rainbow trout 96-h LC₅₀ 1800 mg/L; Mysis shrimp 96-h LC₅₀ 17.4 mg/L

ROUNDUP: Earthworm LC₅₀ in soil, >5000 mg/kg; Honey bee, oral LD₅₀ >100 μg/bee, topical LD₅₀ >100 μg/bee; Daphnia 48-h LC₅₀ 5.3-37 mg/L; Bluegill sunfish 96-h LC₅₀ 5.8-14 mg/L; Carp 96-h LC₅₀ 19.7 mg/L; Catfish 96-h LC₅₀ 16 mg/L; Fathead minnow 96-h LC₅₀ 9.4 mg/L; Rainbow trout 96-h LC₅₀ 8.2-26 mg/L; Crayfish 96-h LC₅₀, >1000 mg/L

Use classification: General use

SYNTHESIS AND ANALYTICAL METHODS

Synthesis: NA

Purification of technical: Recrystallize three times from water

Analytical methods: Assay method for formulated product uses HPLC. Separation is obtained using
a strong anion exchange column and a phosphate buffered mobile phase. AOAC Official Method is 983.10.

Historical: Herbicidal activity was first reported in 1971 (2). Glyphosate-isopropylammonium salt and glyphosate-sesquisodium salt were introduced by Monsanto Company. The trimethylsulfonium salt was introduced in Spain in 1989 by ICI Agrochemicals. U.S. patent 3,799,758 was awarded to Monsanto. European patent 53,871 and U.S. patent 4,315,765 both were awarded to ICI.

MANUFACTURER(S) AND INFORMATION SOURCE(S)
Industry source(s): BASF; Cheminova; Dow AgroSciences; Drexel; Helena; Makhteshim Agan; Monsanto; Syngenta Crop Protection
Reference(s):