Table S1.Soil physical and chemical properties.

Year	Alkaline-hydrolyzable nitrogen ($mg \cdot kg^{-1}$)	Fast-acting phosphorus ($mg \cdot kg^{-1}$)	Fast-acting potassium ($mg \cdot kg^{-1}$)	Organic matter content ($g \cdot kg^{-1}$)	pH
2022	151.2	31.21	201.2	31.81	6.26
2023	143.63	30.96	182	31.26	6.22
2024	145.36	30.75	186.1	31.52	6.24

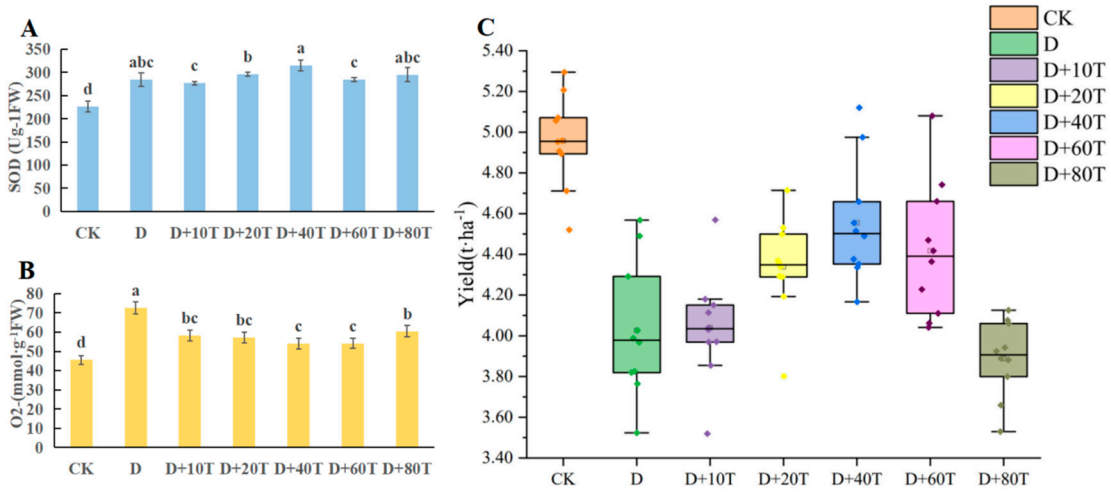


Figure S1. Preliminary screening of betaine concentrations.

Table S2.Three-way ANOVA results for soybean yield and its contributing factors.

Source of variation	Pod number F(df)	P-value	Seeds per plant F(df)	P-value	Seed weight F(df)	P-value	Yield F(df)	P-value
Year (Y)	18.620 (2,24)	0.00001 3	15.370 (2,24)	0.00005	21.450 (2,24)	0.00000 5	24.180 (2,24)	0.00000 2
Treatment (T)	32.510 (1,24)	0.00000 7	26.730 (1,24)	0.00002 7	35.620 (1,24)	0.00000 4	42.630 (1,24)	0.00000 1
Betaine (B)	12.460 (1,24)	0.00171 1	5.820 (1,24)	0.02384 9	11.350 (1,24)	0.00254 4	16.420 (1,24)	0.00046 2
Y × T	1.260 (2,24)	0.30175 4	1.480 (2,24)	0.24768 3	1.170 (2,24)	0.32745	1.310 (2,24)	0.28842 9
Y × B	0.830 (2,24)	0.44818 3	1.120 (2,24)	0.34274 3	0.960 (2,24)	0.39711 4	0.740 (2,24)	0.48768 8
T × B	0.720 (1,24)	0.40452 8	5.310 (1,24)	0.03016 6	14.270 (1,24)	0.00092 3	8.760 (1,24)	0.00682 8

Y × T × B	0.580 (2,24)	0.567554	0.910 (2,24)	0.415968	1.060 (2,24)	0.362124	0.690 (2,24)	0.511253

Note: F-statistics are followed by numerator and denominator degrees of freedom in parentheses. Y, year; T, treatment; B, betaine application.

Table S3.The effect of betaine root irrigation on material translocation in soybrans under drought stress

Treatment	Biomass during the granulation period ($g \cdot m^{-2}$)	Mature biomass($g \cdot m^{-2}$)	Harvest Index	Material Translocation Amount($g \cdot m^{-2}$)	MTR(%)	MCR(%)	MACR(%)
CK	901.12a	863.12a	0.43a	38.00b	4.22a	9.24b	43.44d
CK++T	903.53a	860.35a	0.43a	43.18a	4.78a	10.72a	45.9c
D	801.96c	776.42c	0.41a	25.54c	3.19c	7.52d	47.06a
D+T	840.96b	808.89b	0.43a	32.06b	3.81b	8.43c	46.23b

Table S4.The effect of betaine root irrigstion on nitrogen translocation in soybeans under droght stress

Treatment	Nitrogen content dueing the grain stage(mg·g)	Mature stage nitrogen content.(mg·g)	Accumulation of nitrogen dueing the grain filling stage(g/plant)	Accumulation og mature nitrogen(g/plant)	NUE(%)	NUP(kg/kg)
CK	11.49a	13.55a	1.35a	2.09a	35.94a	22.68c
CK+T	11.81a	12.95a	1.26a	1.92a	31.15a	27.36b
D	10.71b	11.40b	1.02c	1.44c	17.19c	31.45a
D+T	10.73b	11.77b	1.12b	1.67b	23.62b	30.99a

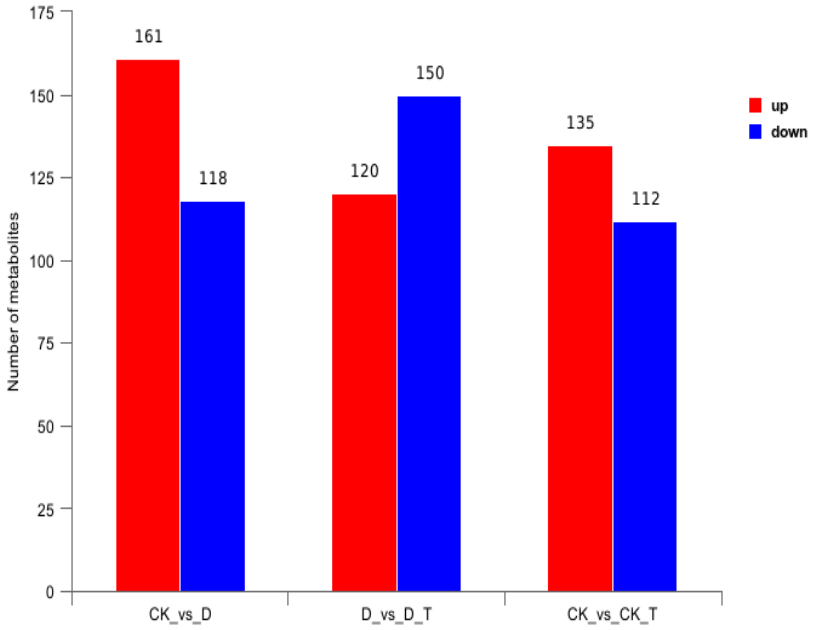


Figure S2. Histogram of differential metabolites in soybeans under drought stress with betaine root irrigation. CK (normal water supply treatment), CK + T (normal water supply + betaine root irrigation), D (drought stress treatment), D + T (drought stress treatment + betaine root irrigation).

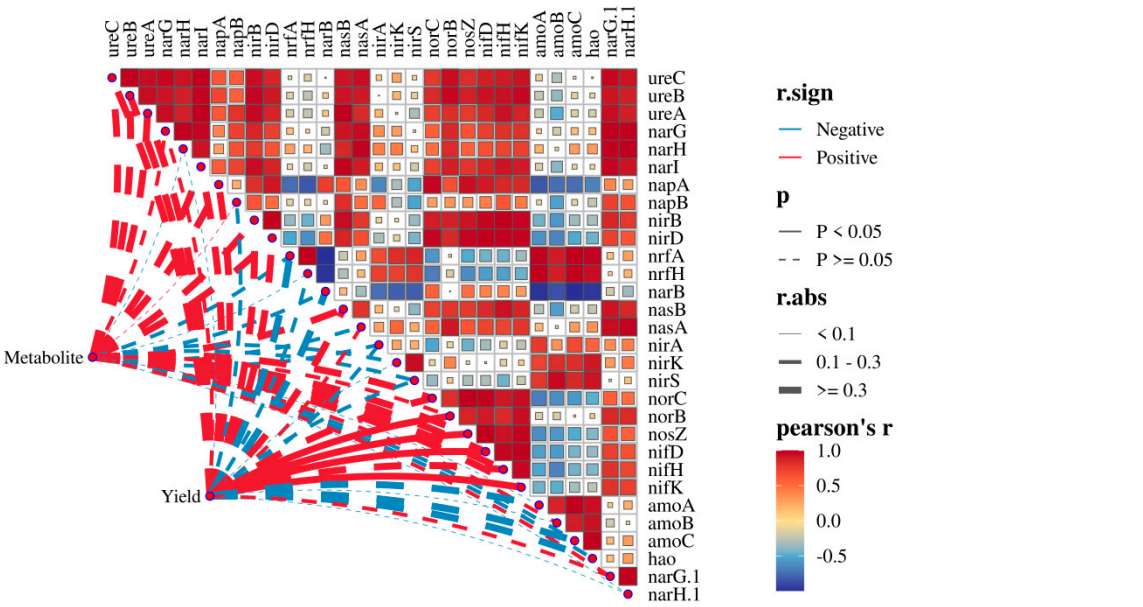


Figure S3. Correlation analysis among metabolites, yield, and nitrogen-cycling genes.

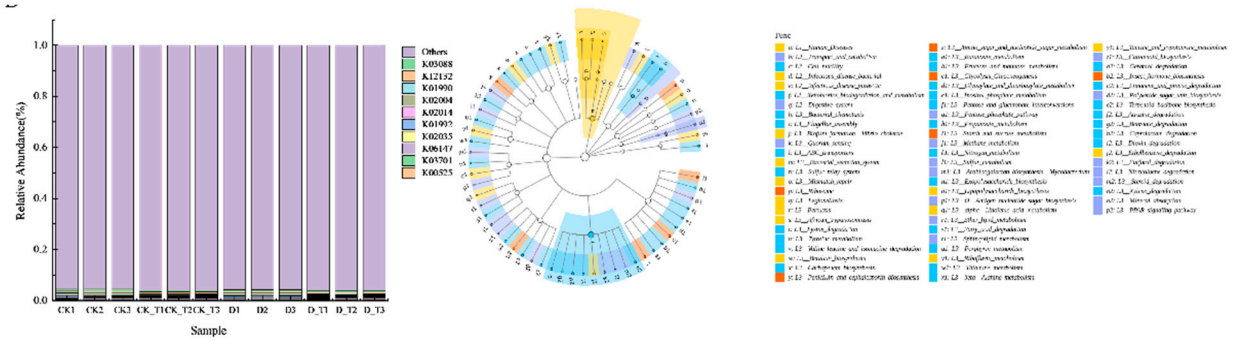


Figure S4. Effects of root application of betaine on soil metagenomics of soybean under drought stress. functional composition bar chart; LEfSe analysis. CK + T, normal water supply + betaine root application; D, drought stress; D + T, drought stress + betaine root application; *n* = 3.