Form of nitrogen input dominates N effects on root growth and soil aggregation: a meta-analysis

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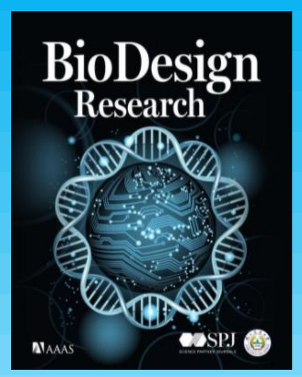

Introduction

Anthropogenic reactive nitrogen (N) input, largely from intensive applications of N fertilizers and fossil-fuel combustion, has overtaken natural biological N fixation as the largest N source to terrestrial ecosystems. Because plant productivity in most terrestrial ecosystems is N-limited, N input often stimulates plant CO_2 uptake and may increase ecosystem C sequestration. Because soil organic C is the largest active C pool on the Earth's surface, small changes in soil C induced by climate change factors such as reactive N input may trigger significant changes in the global C cycle.

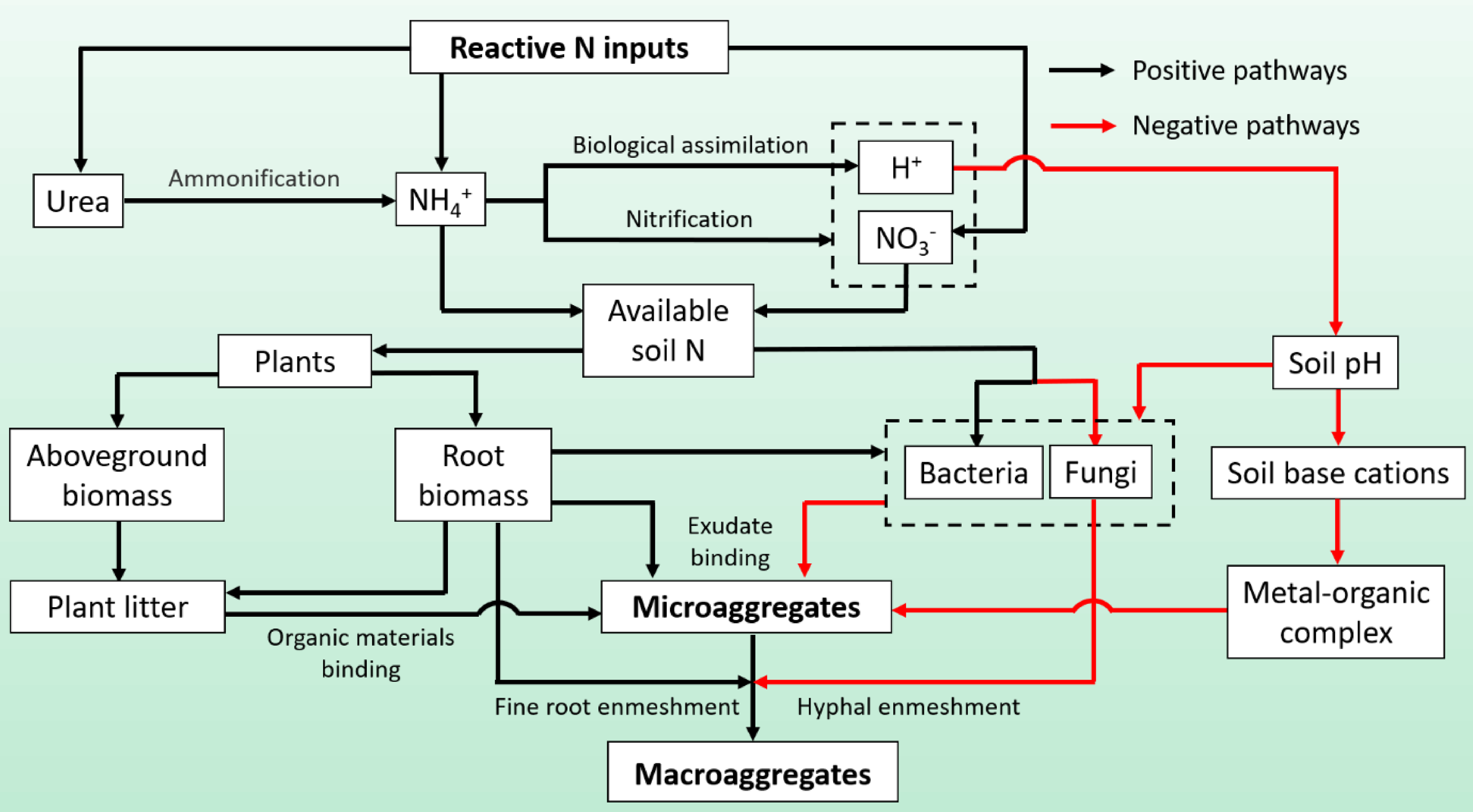

Figure 1 Conceptual model depicting the mechanisms that explain effects of reactive N input on soil aggregation. Black arrows refer to positive effects and red arrows refer to negative effects.

Reactive N input affects many of these processes which may cascade to affect soil aggregate formation and stability (Figure 1). On one hand, increased available soil N promotes plant growth increasing organic residue inputs such as litterfall, root sloughing and exudates. Consequently, increased plant-derived C promotes the formation of organic-mineral complexes that function as nuclei of microaggregates. Also, N-enhancement of plant photosynthesis often allows plant to allocate more photosynthates to roots and their associated mycorrhizal fungi, which may physically benefit soil macroaggregate formation via fine root and/or hyphal enmeshment of microaggregates. On the other hand, N input may suppress soil aggregation through reducing organo-mineral complexes due to N-induced soil acidification and losses of base cations (i.e., Ca^{2+} and Mg^{2+}). Also, soil acidification, induced by chronic N input and associated dissolution and leaching of nutrient may often limit microbial growth, extracellular polymeric substance (EPS) secretion and fungal hyphal growth, further suppressing soil aggregation.

Hypotheses:

(1) N input would promote the formation and stability of macroaggregates mainly through increasing plant root growth.
(2) The form of N input would significantly modulate the N impact with urea-N promoting, and NH_4^+-N and NO_3^--N suppressing soil aggregation.

Materials and methods

We synthesized the diverse, even contrasting impacts of reactive N input on soil aggregation through meta-analysis of experimental results from global terrestrial ecosystems, which appeared in 87 peer-reviewed papers, at 88 sites (Figure 2).

Mean weight diameter (MWD) values, denoting aggregate stability, were calculated in accordance with the formula:

$$\mathrm{MWD} = \sum d * m$$

where d is the mean diameter of the two sieves (mm) and m is relative fraction mass of aggregates (%).

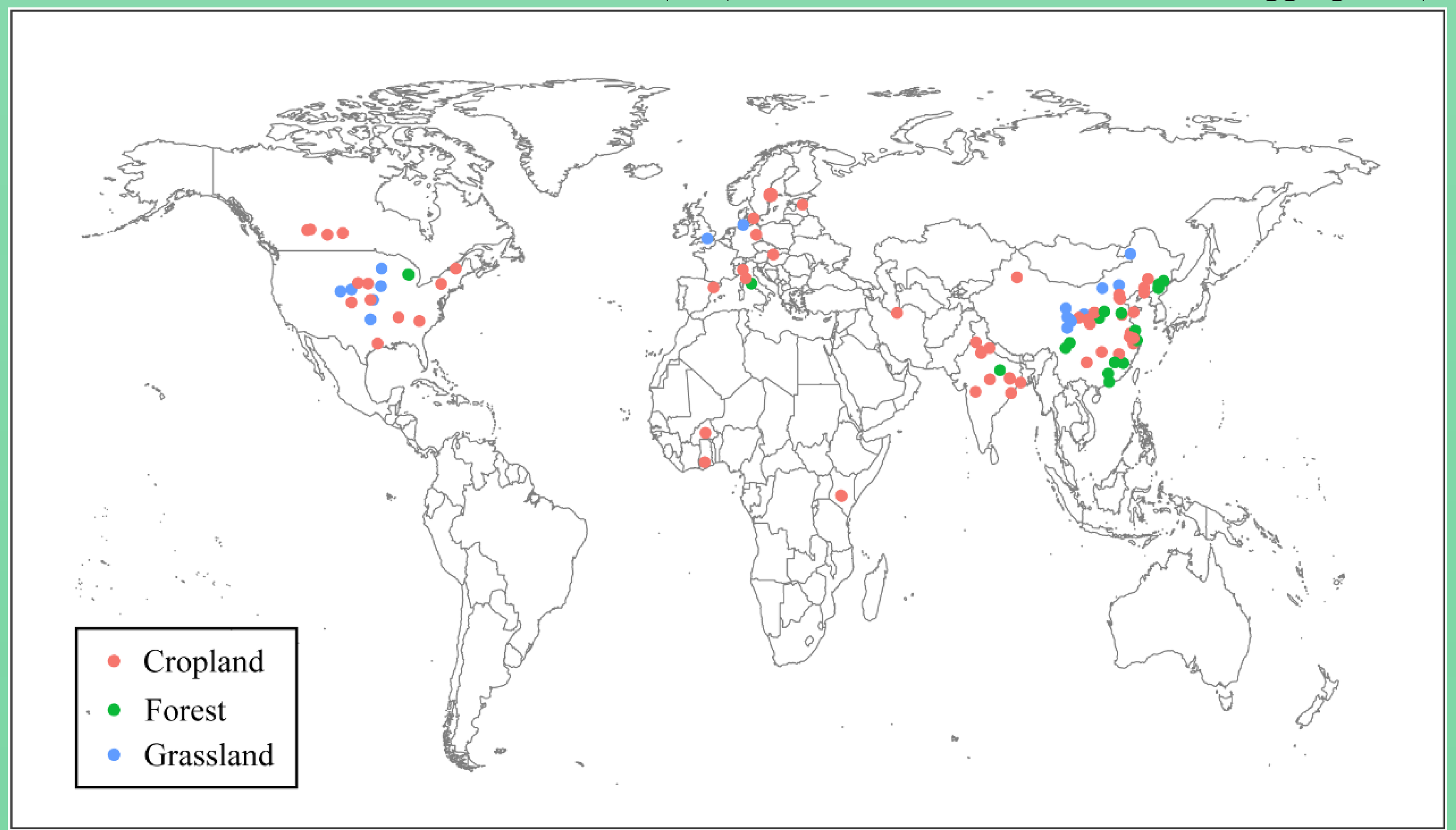

Figure 2 Global distribution of N addition experiments included in this meta-analysis.

Results

Reactive N input significantly enhanced the biomass of plant shoots (+55.4%) and roots (+12.5%) (Figures 3 and 5). It is also significantly increased the mass proportion of macroaggregates (> 250 μm) and thus mean weight diameter (MWD) of soil aggregates (+5.4%) (Figures 3 and 5). In contrast, it had no significant effects on microaggregate (< 250 μm) and microbial biomass (Figure 3), while significantly decreased soil pH (-6.1%). In addition, the response ratio of mean weight diameter (MWD) of soil aggregates increased significantly with the response ratio of root biomass ($P < 0.05$) and microbial biomass ($P < 0.05$), but not with aboveground plant biomass ($P = 0.07$) and soil pH ($P = 0.77$).

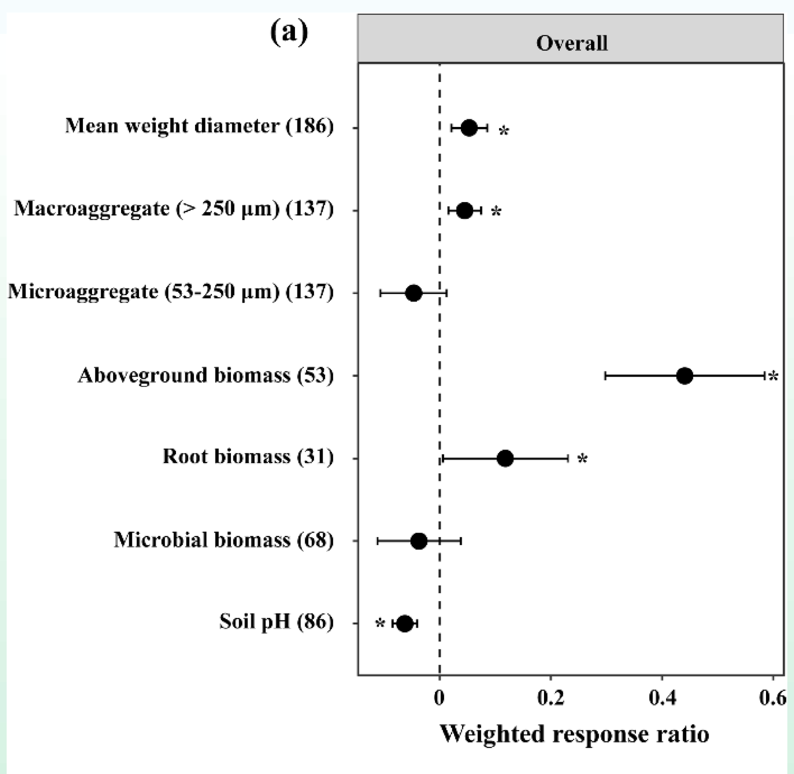

Figure 3 Overall weighted response ratio (RR) of mean weight diameter (MWD), macroaggregate (> 250 μm), microaggregate (53–250 μm), aboveground biomass, root biomass, microbial biomass, and soil pH values in response to N input. The number of observations in each group is shown in parentheses. Bars represent RR ± 95% confidence intervals and the vertical lines were drawn at RR = 0. Asterisks represent significant difference from zero ($P < 0.05$).

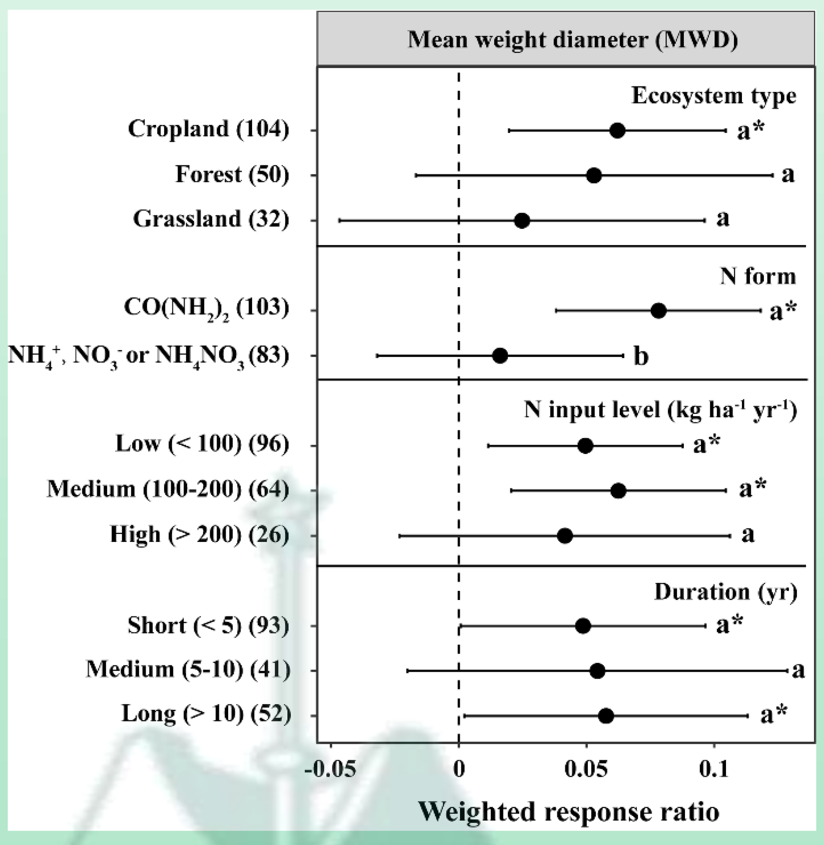

Figure 4 Weighted RR in response to N input with three ecosystem types (cropland, forest, and grassland), two N forms (urea and inorganic forms), three N input levels (< 100, 100–200, and > 200 kg ha^{2} year^{-1}) and three durations of N application (< 5 yr, 5–10 yr, and > 10 yr).

The rate of N input also affected its impact on aggregates: low (< 100 kg N ha^{-1} yr^{-1}) to moderate N input (100–200 kg N ha^{-1} yr^{-1}) significantly increased MWD but high input (> 200 kg ha^{-1} yr^{-1}) did not have significant effects. There were no significant differences in N effects on MWD among different fertilization durations (Figure 4). Nitrogen input significantly promoted soil aggregation in croplands ($P < 0.05$) but had no significant effect in forests and grasslands (Figure 4).

The form of N input significantly influenced the N effect on root biomass ($P < 0.05$), microbial biomass ($P < 0.05$), and MWD of soil aggregates ($P < 0.05$, Table 2, Figure 4). Urea form of N significantly increased aboveground (+62.8%) and root biomass (+20.5%), and significantly enhanced macroaggregate (> 250 μm) (+6.9%) and MWD of soil aggregates (+8.1%) (Figure 5). It also significantly reduced soil pH (-6.7%) and the proportion of microaggregate (< 250 μm) (-9.4%), but had no effect on soil microbial biomass. In comparison, inorganic N fertilizers (combined NH_4^+, NO_3^-, NH_4NO_3 form) did not significantly affect root biomass, proportion of macroaggregate and microaggregate, MWD of soil aggregates, although they significantly increased aboveground biomass (+33.9%) (Figure 5). Also, they significantly reduced microbial biomass (-12.0%) and soil pH (-5.5%) (Figure 5).

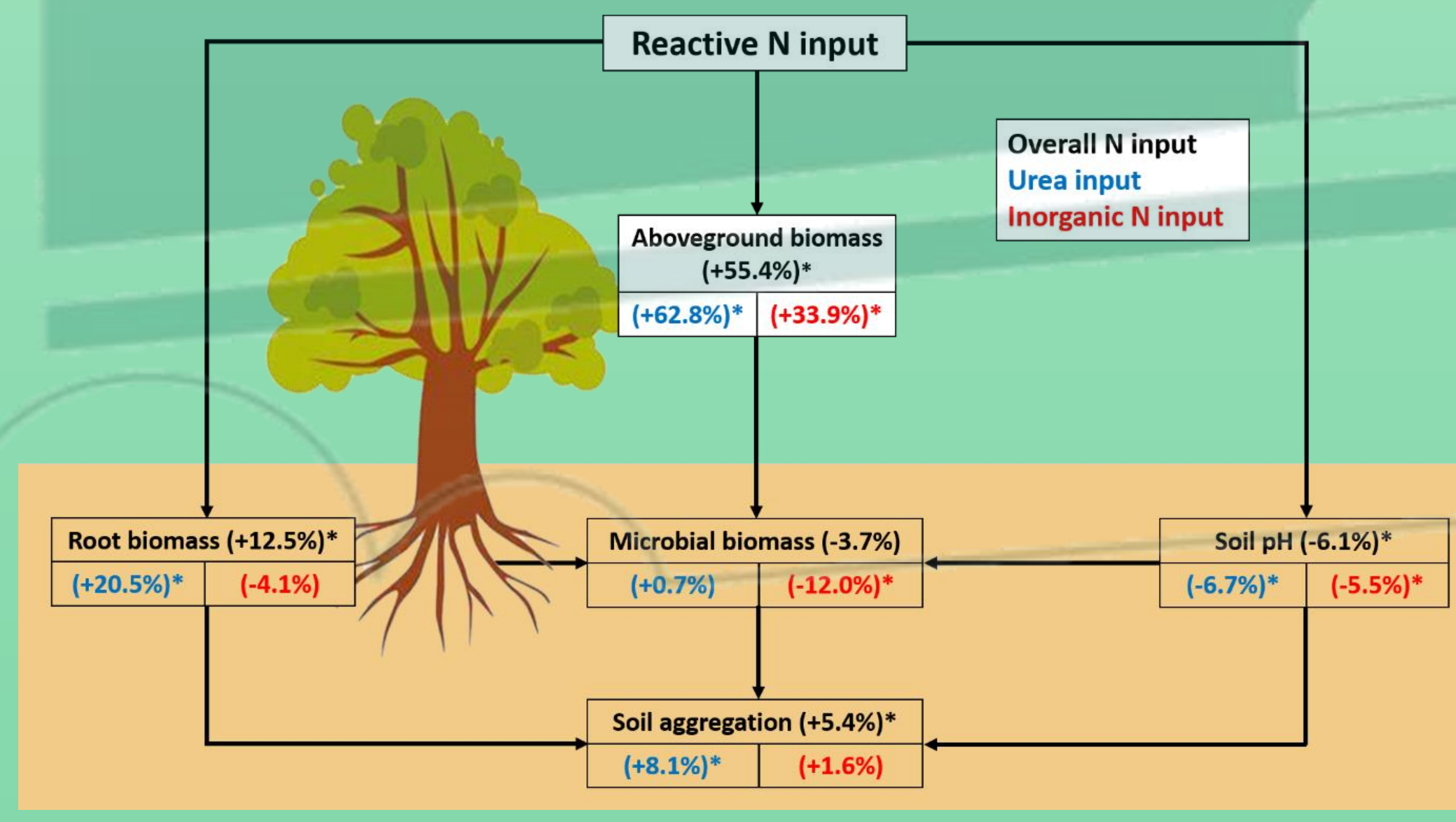

Figure 5 Schematic figure summarizing the relationship between N input and soil aggregation discovered in this study. Numbers in rectangles represent weighted percentage changes in aboveground and root biomass, microbial biomass, and soil pH after N input. The black numbers showed overall weighted percentage changes with N input, and blue and red numbers showed changes with urea and inorganic N input, respectively. The asterisks (*) indicate significant effects ($P < 0.05$).

Conclusions

- **N input enhanced aggregate formation and stability likely by increasing root growth.**
- **N form dominated the N effect on root biomass and soil aggregation.**
- **N-promotion of soil aggregation occurred mainly in croplands with moderate N input.**

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