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# Crop response to nitrogen-phosphorus colimitation: theory, experimental evidences, mechanisms, and models. A review

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## ▶ To cite this version:

HAL Id: hal-04643912
https://hal.inrae.fr/hal-04643912v1

Submitted on 29 Jul 2024

1 Tables for : **Crop response to nitrogen-phosphorus colimitation: theory, experimental evidences,**

2 **mechanisms, and models. A review**

3 Journal: Agronomy for Sustainable Development

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9

10 **List of tables:**

11

**Table. 1**

| Crop | Scientific name | Botanical Family | N response | P response | NxP effect | Growth response Pattern | Type of colimitation | Reference |
|---|---|---|---|---|---|---|---|---|
| Tomato | *Lycopersicum esculentum* L. | Solanaceae | Yes | Yes | No | MLH | | Abu-Alrub et al., 2019 |
| Barley | *Hordeum vulgare* L. | Poaceae | Yes | Yes | No | MLH | | Al-Ajlouni et al. 2010 |
| Kale (Site 2) | *Brassica oleracea* var. acephala | Brassicaceae | Yes | Yes | No | MLH | | Chakwizira et al. 2009 |
| Swede (Site 2) | *Brassica napus* subsp. *napobrassica* | Brassicaceae | Yes | Yes | No | MLH | | Chakwizira et al. 2011 |
| Common bean | *Phaseolus vulgaris* L. | Fabaceae | Yes | Yes | No | MLH | | Chekanai et al. 2018 |
| Wheat | *Triticum aestivum* L. | Poaceae | Yes | Yes | No | MLH | Independent Additive | Girma et al. 2007 |
| Rice | *Oryza sativa* L. | Poaceae | Yes | Yes | No | MLH | | Serme et al. 2018 |
| Potato | *Solanum tuberosum* L. | Solanaceae | Yes | Yes | No | MLH | | Setu et Mitiku 2019 |
| Groundnut | *Arachis hypogaea* L. | Fabaceae | Yes | Yes | No | MLH | | Tekulu et al. 2020 |
| Sorghum | *Sorghum bicolor* L. Moench | Poaceae | Yes | Yes | No | MLH | | Wang et al. 2017 |
| Potato | *Solanum tuberosum* L. | Solanaceae | Yes | Yes | No | MLH | | Zewide et al. 2012 |
| Canola | *Brassica napus* L. | Brassicaceae | Yes | Yes | No | MLH | | Nuttall et al. 1992 |
| Canola | *Brassica napus* L. | Brassicaceae | Yes | Yes | Yes | MLH | | Brennan and Bolland 2009 |
| Wheat | *Triticum aestivum* L. | Poaceae | Yes | Yes | Yes | MLH | Independent Super-additive | Brennan and Bolland 2009 |
| Kale (Site 1) | *Brassica oleracea* var. acephala | Brassicaceae | Yes | Yes | Yes | MLH | | Chakwizira et al. 2009 |
| Alfalfa | *Medicago sativa* L. | Fabaceae | Yes | Yes | Yes | MLH | | Fan et al. 2016 |

| Common Name | Scientific Name | Family | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|
| Maize | *Zea mays* L. | Poaceae | Yes | Yes | Yes | MLH | | Getnet et Dugassa 2018 |
| Safflower | *Carthamus tinctorius* L. | Asteraceae | Yes | Yes | Yes | MLH | | Golzarfar et al. 2012 |
| Buckwheat | *Fagopyrum* esculentum Moench | Polygonaceae | Yes | Yes | Yes | MLH | | Ullah et al. 2012 |
| Maize | *Zea mays* L. | Poaceae | Yes | Yes | Yes | MLH | | Kamanga et al. 2014 |
| Potato | *Solamum tuberosum* L. | Solanaceae | Yes | Yes | Yes | MLH | | Nekinike and Dechassa 2018 |
| Egusi Melon | *Citrullus lanatus* (thunb.) Mansf | Cucurbitaceae | Yes | Yes | Yes | MLH | | Olaniyi et al. 2008 |
| Maize | *Zea mays* L. | Poaceae | Yes | Yes | Yes | MLH | | Schlegel and Havlin 2017 |
| Sorghum | *Sorghum bicolor* (L.) Moench | Poaceae | Yes | Yes | Yes | MLH | | Schlegel and Havlin 2020 |
| Mung Bean | Vigna radiata L. | Fabaceae | Yes | Yes | Yes | MLH | | Yin et al. 2018 |
| Tef | *Eragrostis* tef (Zuccagni) Trotter | Poaceae | Yes | Yes | Yes | MLH | Independent Super-additive (Low Input) / Independent Sub-Additive (High Input) | Dereje et al. 2018 |
| Faba bean | *Vicia faba* L. | Fabaceae | Yes | Yes | Yes | MLH | | Adak and Kibritici 2016 |
| Kale (Site 3) | *Brassica oleracea* var. acephala | Brassicaceae | Yes | No | Yes | LM | | Chakwizira et al. 2009 |
| Swede (Site 1) | *Brassica napus* subsp. napobrassica | Brassicaceae | Yes | No | Yes | LM | Serial N | Chakwizira et al. 2011 |
| Sesame | *Sesamum indicum* L. | Pedaliaceae | Yes | No | Yes | LM | | El Mahdi et al. 2008 |
| Globe Artichoke | *Cynara cardunculus* L. var. scolymus (L.) Fiori | Asteraceae | Yes | No | Yes | LM | | Ierna et al. 2006 |
| Wheat | *Triticum aestivum* L. | Poaceae | No | Yes | Yes | LM | Serial P | Takahashi and Anwar 2005 |

18

3

**Table 2.**

| Crop Model | APSIM | DSSAT | EPIC | QUEFTS | PARNJIB |
|---|---|---|---|---|---|
| Model category | Semimechanistic | Semimechanistic | Semimechanistic | Hybrid | Empirical |
| Spatial Scale | Field | Field | Field | Field | Field |
| General Handling of N:P nutrient statues | | | | | |
| Stoichiometric Factors N/P | No | Limit P uptake | NR | NR | NR |
| N-P colimitation management | Law of the minimum | Law of the minimum | Law of the minimum | Mean of the potential yields | Reduction factor accounting all stresses |
| Soil and root representation | | | | | |
| Soil representation | 1D profile | 1D profile | 1D profile | No spatialization | No spatialization |
| Root representation | Root depth, density and Biomass per layer | Root depth, density per layer, Root radius | Rooting depth and weight per layer | NR | NR |
| Root response to N deficiency | NR | Reduce shoot:root | NR | NR | NR |
| Root response to P deficiency | NR | Partitioning Coef | NR | NR | NR |
| pH simulation | Computed/Proton Balance | Input | Computed | Input | Input |
| Rhizospheric Processes | | | | | |
| Symbiotic N2 fixation | R | R | R | NR | NR |
| Nodules representation | Implicit | R | NR | NR | NR |
| N effect on N2 fixation | Triggered by N deficiency/No direct effect on the rate | Triggered by N deficiency/No direct effect on the rate | Inhibition | NR | NR |
| P effect on N2 fixation | NR | NR | NR | NR | NR |
| N effect on APase Secretion | NR | NR | NR | NR | NR |
| P effect on APase Secretion | NR | NR | NR | NR | NR |
| Organic acid secretion | Citrate only | NR | NR | NR | NR |
| Mycorrhizae | NR | NR | NR | NR | NR |
| References | Delve et al. 2009 ; Keating et al. 2003 ; Robertson et al. 2002 | Dzotsi et al. 2010 ; Jones et al. 2003 ; Boote et al. 2008 | Sharpley and Williams 1990 Jones et al. 1984 | Sattari et al. 2014 | Reid et al. 2002 |