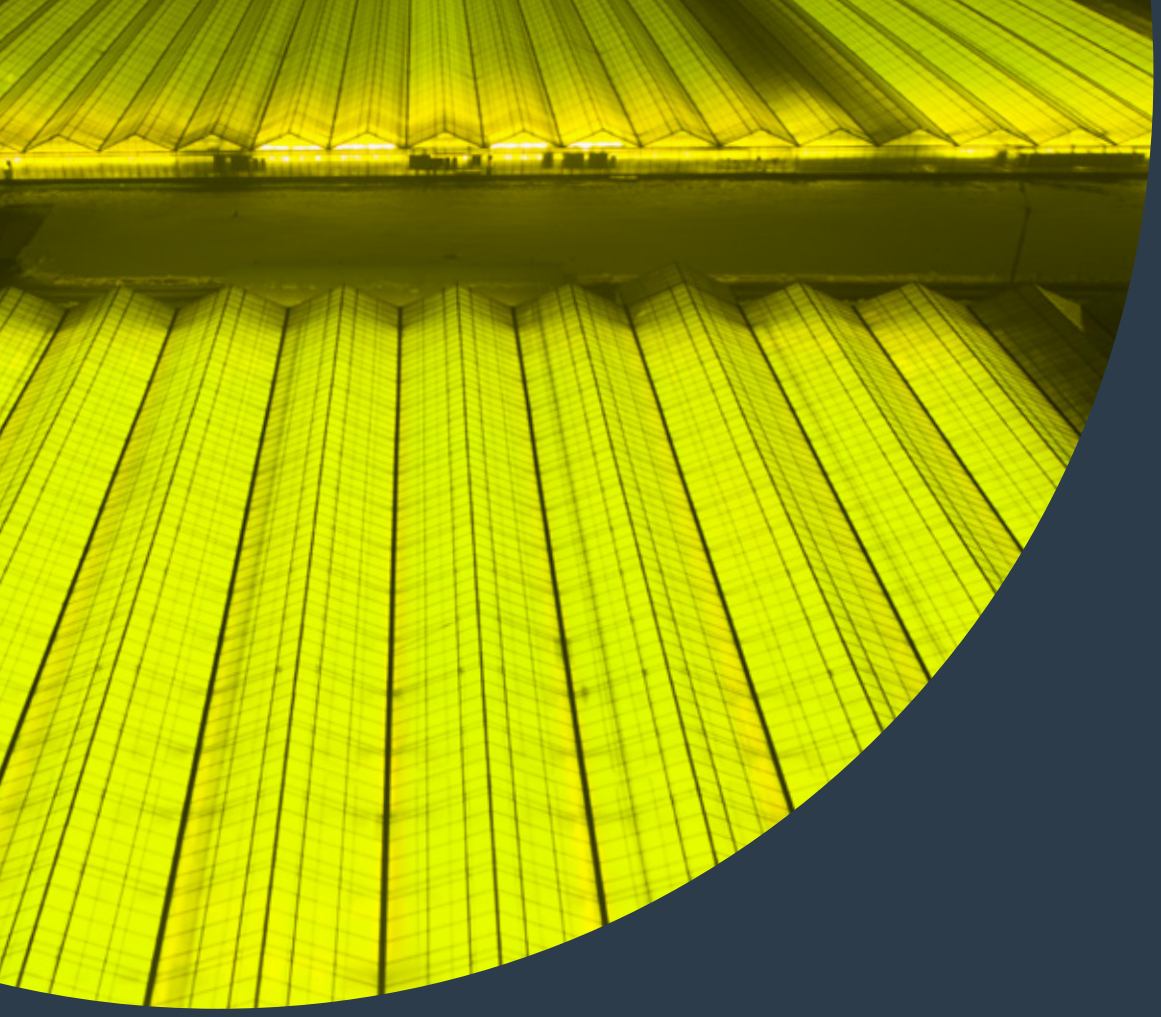

ProAqueous
Agricultural
Solutions

CO2 Enriched Water

What is ProAqueous CO2 Enriched Water?

CO2 Enriched Water is a new way for growers to provide an essential resource for their crops.

Enriching levels of CO2 in the crop environment boosts rates of photosynthesis environment boosts rates of photosynthesis and promotes accelerated growth. This leads to the shortening of harvest times and an increased yield within the same footprint. **CO2 Enriched Water** offers a way to provide CO2 for crops in an entirely new way that overcomes many of the difficulties of existing approaches. Conventional CO2 enrichment relies on using flue gases from boilers or combined heat and power systems (typically natural gas-fired) but the high set up costs and poor economy of scale renders this approach inaccessible to many growers. These methodologies also have a large carbon footprint. Alternative methods, such as Limestone-based leaf application systems, are marketed for localised CO2 enrichment, but these are slow acting and will require frequent reapplication if any sustained benefit is to be achieved.

CO2 Enriched Water suffers none of these drawbacks and hence the technology is particularly suited for high value crops grown under protection such as soft fruit and leafy salads as well as traditional glasshouse growing operations and vertical farming set ups.

Proaqueous CO2 Enriched Water – A New Approach to CO2 Enrichment Fertilisation

The UK horticulture sector is typified by the production of high quality, high value fresh produce that can be marketed at a premium to UK consumers.

Growers are continually looking for ways to improve yields (both in terms of volume and quality), reduce wastage and increase the efficiency of their production. Providing the growing crop with optimum levels of resources (water, light, nutrients and CO2) is essential in enabling the crop to reach its maximum potential.

Water, light and nutrients (the normal limiting factors in natural growing conditions) can all be optimised relatively easily with CO2 being the factor that is most difficult to influence. This **CO2 Enriched Water** system works best where these other factors have already been optimised.

CO2 Enriched Water offers growers a new way to manipulate the growing environment, accessing the benefits of CO2 enrichment through a new low-tech, low-cost route that is applicable in a wide range of settings. This system is therefore appropriate where conventional CO2 enrichment would have been unviable as well as being suitable as a replacement for existing CO2 enrichment systems. The Proaqueous **CO2 Enriched Water** system has a negligible carbon footprint.

Carbon dioxide (CO2) is one of the basic resources required by plants – when combined with water and sunlight plants utilise CO2 from the atmosphere to carry out photosynthesis. CO2 is absorbed directly from the atmosphere – in sunlight well-watered plants will open

microscopic pores (stomata) in the leaf surface, allowing CO2 to diffuse into intercellular spaces in the leaf. After passing into solution on the moist intercellular surfaces, CO2 diffuses into the chloroplasts in the plant cells where it is fixed into simple sugars using energy that has been captured from sunlight. These sugars can then be converted to new biomass for growth, expended to produce the energy required to absorb nutrients from the soil or used to sweeten fruits.

The rate of photosynthesis varies with the concentration of CO2 in the atmosphere around the plant. Under conditions of high light CO2 concentrations can be depleted below typical ambient concentrations of 400 ppm, which exponentially reduces the rate of photosynthesis. The ProAqueous **CO2 Enriched Water** creates an artificially ambient condition that is equivalent to 1,500 ppm CO2 concentrations. CO2 depletion can cause significant growth impairment for crops grown under plastic or glass where gas exchange with the outside atmosphere may be limited, particularly in high summer when the crops should be at their most productive. Reduced rates of photosynthesis will reduce the amount of sugars available to the plant, slowing growth and lowering yields if this occurs over a sustained period of time.

Conversely, rates of photosynthesis will show a significant increase if concentrations of CO2 can be raised above ambient through the application of additional CO2 to the growing environment (CO2 enrichment). This effect is exploited by the commercial tomato industry where it is standard practice to increase CO2 levels to 800 – 1000 ppm, allowing yields to be increased by upwards of 30%. Increases above this level are unlikely to offer meaningful returns as the plants are limited by other inputs (light), but provides a background

against which all other resources (water, temperature, light and nutrients) can be utilised by the crop with optimum efficiency.

Higher levels of CO2 increase the rates of photosynthesis, making greater quantities of sugar available for the crop to convert into yield. Increasing the localised concentration of CO2 may have additional benefits besides enhancement of net photosynthesis. Higher levels of intercellular CO2 within the leaf can promote stomatal closure, reducing the loss of water out of the leaf. In irrigated systems this may improve water use efficiency, while boosting a crop's resilience to drought stress in the open field.

While the benefits of CO2 enrichment are clear, uptake has largely been constrained to a few key crop groups, largely as a result of the costs and complexity of conventional CO2 dosing infrastructureand complexity of conventional CO2 dosing systems. Conventional approaches are generally only realistic and cost effective on large-scale sites, so **CO2 Enriched Water** represents a step change in that the technology is scalable to a variety of grower holding sizes and types. This will enable growers to unlock the benefits of CO2 enrichment to enhance yield outputs by targeted management of a key resource.

ProAqueous CO2 Enriched Water – How does it work?

Atmospheric enrichment of CO2 is an inherently wasteful process to maintain target concentrations in a glasshouse environment as a result of rapid loss to the outer atmosphere.

CO2 Enriched Water represents an alternative method of application that supplies CO2 directly to the plant without relying on slow, wasteful, passive mixing processes. CO2 is concentrated in water through a special process which is then applied to the leaf surface through an overhead misting system. The **CO2 Enriched Water** is applied over a brief period (typically <1 minute) at up to four time points over the day. The targeted application of CO2 to the crop means that much smaller quantities of CO2 can be applied to achieve the same effect when compared with atmospheric enrichment. In addition, it is easier to target enrichment to periods where the crop is most able to use it (e.g. during periods of high sunlight) when compared with gas enrichment which shows a considerable time delay between application and effect. By providing CO2 enrichment to their crops growers will be able to access accelerated growth rates, greater yield returns, shorter windows of crop harvests and improved product quality.

CO2 Enriched Water is a super saturated solution of CO2 dissolved water which is applied as a mist over the crop. When this is applied to the leaf surface the CO2 is made available to the plant through two key routes. Firstly, the CO2 in solution can pass directly into the intercellular space in the leaf as the **CO2 Enriched Water** is absorbed into the leaf. Secondly, as the CO2 comes out of solution on the leaf surface it will create a localised bubble of CO2-enriched atmosphere around the leaf. This CO2

can be absorbed directly by the plant and used in photosynthesis.

To achieve target CO2 concentrations throughout using a traditional Combined Heat and Power (CHP) system the crop growers must rely on convection currents or passive diffusion to mix in the applied CO2. This often creates significant differences in CO2 concentration across the growing environment, with levels varying from >1000 ppm at floor level to <600 ppm at the top of the canopy. This heterogeneity means that the most productive canopy layers at the top of the crop are often exposed to lower-than-desirable concentrations of CO2 despite high levels of dosing. In tomato production the high glasshouse ceilings that are required to accommodate a crop grown at a height of up to 10ft creates a large airspace. Enrichment in this fashion requires application rates of around 300 kg/ha/hour to achieve concentrations of 800 – 1000 ppm. This is further impacted by the need for frequent venting to control temperature and humidity, particularly in the summer season. In order to achieve this level of application significant investment in infrastructure is required, with growers installing CHP units in excess of 36MW.

Besides the technical costs of installing and maintaining these systems, the cost of CO2 provision can vary between £125/tonne for pure food grade CO2 to around £80/tonne for CHP-sourced CO2, although the cost of the latter can vary significantly on the cost of energy (both raw materials and of the marketed electricity) and how the heat produced is utilised. These barriers have greatly restricted the uptake of CO2 enrichment in commercial horticulture where investment on this scale is only possible for the largest of growers and for crops of the highest value. As CO2 is mixed in as a gas, the vast proportion (>80%) is lost to the environment, requiring dosage rates of c. 300 kg CO2/ha/hr to achieve 800 – 1000ppm.

What are the Advantages of using ProAqueous CO2 Enriched Water?

CO2 Enriched Water is a unique product that offers growers the potential to provide CO2 enrichment for their crops without facing the economic or technological challenges of conventional CO2 enrichment.

This is especially relevant for growers who are not able to utilise the heat/market the electricity that is produced by conventional CO2 production, as use of these outputs are required if CHP CO2 enrichment is to be economical. It also offers greater potential for CO2 enrichment compared with lime-based systems. As the **CO2 Enriched Water** is applied through an independent, closed loop irrigation/misting system the labour costs of application are minimal. This also means that far more frequent applications can be delivered to the crop, giving greater potential for CO2 enrichment in the long run compared with conventional or solid-state CO2 enrichment approaches.

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