has made it possible to breed and cultivate food crop species far from their centers of origin, and in some cases into vastly different climatic zones where they would not be able to survive on their own without the hand of humankind. Rice, maize, and wheat, originating from Vavilovian centers II, III and VII (Figure 1), respectively, are widely grown and account for 60% of the world’s food energy intake. While the collection of 600 economically important crop species seems like a substantial number, it is thought that the documented edible crop species in cultivation totals about 7,000 species (Khoshbakht and Hammer, 2008). Yet, there is another 28,000 cultivated species that belong to an “amenity horticulture” grouping of plants connected with gardening and landscaping (Khoshbakht and Hammer, 2008). In contrast to the important food crop plants with origins from the Vavilovian centers, amenity horticulture species associated with landscaping and gardening originate from a much wider geographic distribution (Figure 1).

We understand the reason for the cultivation of food crop species, for the energy and essential nutrients they provide, but what about those in the amenity horticulture grouping? Is it the aesthetic or other desired sensory characteristics, or is there something more that underlies why 80% of the cultivated species have little or no food related purpose? A growing body of empirical evidence suggests that plants provide additional health benefits, over and above that of providing nutrition, consuming carbon dioxide, generating oxygen, and reducing airborne particulate pollutants. Besides serving as a main food source and as an ecological bioregenerative system, research continues to demonstrate that interactions with plants provide essential benefits to the health, well-being and longevity of people, wherever they may live. It is a given that plants will serve multiple roles in long-duration spaceflight as people journey ever further from the Vavilovian centers of crop origin.

Abstract: Plants provide people with vital resources necessary to sustain life. Nutrition, vitamins, calories, oxygen, fuel, and medicinal phytochemicals are just a few of the life-supporting plant products, but does our relationship with plants transcend these physical and biochemical products? This review synthesizes some of the extant literature on people-plant interactions, and relates key findings relevant to space exploration and the psychosocial and neurocognitive benefits of plants and nature in daily life. Here, a case is made in support of utilizing plant-mediated therapeutic benefits to mitigate potential psychosocial and neurocognitive decrements associated with long-duration space missions, especially for missions that seek to explore increasingly distant places where ground-based support is limited.

Keywords: Bioregenerative, Cognition, Countermeasure, Food Crop, Horticultural Therapy, Mental Health, Nature, Natural Environment, Psychological Stress, Spaceflight

Introduction

Since Mesolithic times wherever people have journeyed, they have taken their food and favorite plants with them. By the 20th Century it was realized that most of the 600 economically important cultivated crop plants hail from eight Vavilovian geographical centers of origin (Vavilov, 1926; 1935; 1992), representing a small percentage of the total land area of the world. Yet, modern agriculture
Food Crop Production and Bioregenerative Life Support

It was realized early in the space program that extended manned exploration of space would ultimately require farming to support human needs during long-duration space missions (LDSMs) and the colonization of the Moon and Mars. Stowage of enough food was never seen as a viable option for LDSMs. Therefore, Earth-based farming would need to be adapted to meet the requirements of space-based farming (Wheeler and Tibbits 1987; Wheeler et al., 1996a, b; Porterfield et al., 2003; Monje et al., 2003; Poulet et al., 2016). Russian, European, and American scientists were initially concerned with the influence of spaceflight conditions on basic plant growth and development, thus a number of different plant growth systems and environments that would serve as platforms for basic plant biology studies and plant cultivation systems were developed (Fei et al., 2002; Porterfield et al., 2003; Paul et al., 2013; Zabel et al., 2016). Over time, improvements were made to the plant growth systems. However, it became clear there were physical limitations and physical chemical challenges to overcome for successful growth of plants and ultimately for space farming in a microgravity spaceflight environment (Monje et al., 2003). For example, microgravity leading to changes in buoyancy dependent convective transport, increased size of boundary layers and reduced mass transport posed particular challenges for plant growth (Monje et al., 2003). Additionally, manned spaceflight environments were prone to highly elevated CO₂ concentrations (Wheeler et al., 1993; Monje et al., 2003; Law et al., 2010) and generation of volatile organic compounds such as ethylene that had unfavorable plant growth regulating properties necessitating their scrubbing from the atmosphere (Campbell et al., 2001). Currently, the Veggie growth system is in operation on the International Space Station (ISS) and represents the latest version of a spaceflight food production platform (Massa et al., 2016).
On Earth, plants perform a number of bioregenerative ecosystem services, and since the beginning of space exploration, bioregenerative life support systems were thought to be essential for LDSMs (Nichiporovich, 1969; Blüm et al., 1994; Mitchell, 1994; Ferl et al., 2002, Porterfield et al., 2003). Human LDSMs and voyages require uninterrupted supplies of oxygen, water, and food. Bioregenerative food systems are intended to provide not only fresh foods (Perchonok et al., 2012), but at the same time consume carbon dioxide, produce oxygen, and repurpose grey water for crop growth and conversion to water vapor upon passing through and out of the plants. These plant functions are at the heart of embarking on LDSMs and ultimately colonizing the Moon and Mars. Programs like NASA’s controlled ecological life-support system (CELSS) were focused on the goal of developing a plant-based food supply that would be independent from the need for resupply from Earth (MacElroy and Breddt, 1984; Mitchell 1994). Therefore, LDSMs would depend on meeting crew needs for oxygen, water, and food, and maintaining lower ambient carbon dioxide concentrations with the challenges of limited available power and volume. An additional function of bioregenerative food production besides meeting the nutritional needs of the astronauts would be to help maintain their psychological well-being, cognitive performance, and crew cohesiveness and performance. This benefit of the bioregenerative life support system has long been appreciated as a countermeasure to the stressful conditions within the built, confined and isolated environment of a spaceflight vehicle (Neichitailo and Mashinski, 1993; Mitchell, 1994; Ferl et al.; 2002, Porterfield et al.; 2003; Bates et al., 2009; Perchonok et al., 2012), but has received virtually no formal experimental attention.

Spaceflight and Stress

Living in a spacecraft for extended periods is foreign to the life most live on Earth. A spacecraft has several defining characteristics in addition to the absence of gravity and natural diurnal cycles that make long-term habitation difficult, particularly with respect for: 1, isolation; 2, confinement; 3, proximity to a dangerous hostile environment; and 4, lacking a natural biophilic interior environment. On LDSMs the crew is cutoff from direct face-to-face and interpersonal contact with family, friends, and home that electronic video conferencing cannot fully substitute. Spaceflight will also continue for some time into the future to be a continuously risky endeavor where malfunction or accident could potentially be an existential emergency. Physical and emotional challenges can be magnified in a confined environment. Spaceflight vehicles provide very little physical space that therefore limits space for movement, space from people, space for privacy, space from work, space to get away, and space to work through one’s problems (Shepanek, 2005). On Earth, confinements are almost always a punishment, go to your room, go to jail, go to solitary confinement, and are intended to be unpleasant and stressful for the purpose of modifying behavior. The smaller the space of confinement, the greater the unpleasantness and stress of the experience is likely to be.

Psychological stress can be a function and outcome of the magnitude of perceived risk and danger. Our species evolved in a natural world, not in an unnatural man-made built environment. A simulated interplanetary mission to Mars study of six men in an analog environment revealed a diversity of behavioral responses (Basner et al., 2014) with some individuals exhibiting very modest changes, and at least one individual with increasingly more severe behavioral health decrement over time. As we evolved in a 1g world, living in a microgravity environment poses physiological and physical health challenges for flight crews that can negatively impact psychological well-being such as space motion sickness, shifts in body fluid distribution, and vestibular dysfunction (Williams et al., 2009). Furthermore, if E.O. Wilson’s Biophilia Hypothesis is true (Wilson, 1984), then people have an “innate tendency to focus on life and lifelike processes,” and in a broader sense this could be taken to mean we have evolved with an innate need to be in and experience nature. When these and other factors are taken into consideration, it seems reasonable that spaceflight and longer duration space missions could lead to occurrences of mental health disorders and lower cognitive performance of flight crews that could imperil crew cohesiveness, command structure, decision making and ultimately imperil the mission and safety of the crew. Based on post-mission medical interviews and examinations, anxiety and annoyance were the most frequent behavioral symptoms for astronauts from space shuttle missions (Shepanek, 2005). Other behavioral issues reported from spaceflight missions included sleep disorders, reduced energy, attentiveness, and problem solving ability, memory impairment, and increased hostility, boredom, and impulsivity. Palinkas (2001) has reviewed psychosocial issues and concerns related to the psychological and physical characteristics associated with LDSM.

NASA has conducted an Evidence Report (Slack et al., 2015) that evaluated anticipated risks of cognitive, behavioral and psychiatric disorders during LDSMs. Using
evidence gathered from reports of previous spaceflights and ground-based spaceflight simulations, estimates were made on the probabilities of behavioral problems occurring during LDSMs. The report lays out plans to cope with inflight mental health disorders through a series of countermeasures. Inflight countermeasures that relate to this article include: 7) Interior Design (pages 51-52) that will provide a richer sensory environment that is intended to reduce attention fatigue and stress, promote learning, restoration, and engagement in therapeutic interventions; and 8) Leisure Activities (page 52) that engage crewmembers during their time off (Slack et al., 2015). While space vehicles will always be highly limited on available interior space, it is suggested that plants will be included as both a food source and as a therapeutic countermeasure. Nature is also recognized as being restorative, but space limitations will probably allow only simulated nature experiences.

People and Plants

Plants have been a part of the human condition throughout the last two million years, and their role in our evolution, cognitive development and survival supersedes that of all other macro-organisms on the planet. Given our unqualified dependence on plants for so many everyday needs, even in today’s world, it becomes unimaginable to think of what life might hold for us in a world totally devoid of plants. Plants permeate all aspects of our lives, including life-supporting oxygen generation and carbon dioxide consumption, solar energy capture, biological chemical transformation, sustenance and supply of calories, vitamins, essential nutrients and minerals, provision of shelter and production of medicinal compounds; all while serving as defining elements of home, culture, family and our intrinsic well-being. We know plants like we know the members of family; some we know intimately, and others we know only distantly. Like family, plants make us happy, cheerful, fulfilled, comfortable, relaxed, at ease, secure, composed, peaceful, friendly, and social (Kaplan, 1995; Frumkin, 2001; Gonzalez et al., 2011a, b; Kotozaki et al., 2015). In a small adjustment to E.O. Wilson’s Biophilia Hypothesis (1984), where he states that Biophilia is: “the innate tendency to focus on life and lifelike processes” it is suggested here that Biophilia includes: “the innate tendency to focus on [plants] and [plantlike] processes, and the apparent evidence of that envelops us in daily life (Lewis, 1996). Plants provide us with food, and increasingly science is showing that plants are vital to our behavioral health and overall well-being (Ulrich, 1986; Ulrich et al., 1991; Gonzalez et al., 2011a, b; Gonzalez and Kirkevold, 2013; Jo et al., 2013; Bratman et al., 2015; Kotozaki et al., 2015). This article seeks to make the case that for long-duration spaceflights and extraterrestrial habitation; plants will extend ecosystem services to flight and habitat crews beyond recycling resources and meeting nutritional needs, to that of sustaining behavioral health, cognitive performance and overall physical health.

People-Plant Interactions Context and Background

Perhaps it is of value to begin with the obvious. Why do tens of millions of Americans engage in some form of gardening-like or plant care leisure activity, representing about 70% of all households in the U.S. (Butterfield, 2009)? If one asks gardeners, common replies include, because gardening makes them feel better, relaxed, less stressed, happy, at peace, and proud of meaningful work. Furthermore, the massive body of anecdotal evidence for the therapeutic benefits of gardening seems too overwhelming and compelling to not have a biological basis in reality. The notion that physical work in a garden offered mental health benefits was first recognized by Dr. Benjamin Rush in his 1812 book, Medical Inquiries and Observations, Upon the Diseases of the Mind. Additionally, Ashton-Shaeffer and Constant (2005) did a survey of 303 older adults, and identified seven motivational factors of why they engaged in gardening: intellectual engagement, stimulus-avoidance, friendship building, social interaction, physical fitness, skill-development, and creativity. A study by Clayton (2007) examining gardening and connections to nature found that for a population of mostly women spending time outdoors, observing nature, finding relaxation, having pride of effort, and using new plants were motivations for their gardening activities.

More than 40 years ago, Rachel Kaplan suggested that gardening would be a good starting point to understand the psychological benefits of nature experiences (Kaplan, 1973). She suggested that gardening as a source of “fascination” could prompt “involuntary attention” (where involuntary attention is not under the control of the individual, and occurs when the conscious mind shifts focus in response to sudden and important changes in stimulus from the environment, and is less concerned with motives, interests, needs and functional factors) that allows the capacity for “directed attention” to be restored. Directed attention is the voluntary allocation of attention that can be focused selectively in a sustained way to specific information or cognitive processes. In the decades
since the Kaplan study, thousands of studies on the therapeutic benefits of gardening, horticultural therapy, and nature experiences have been published. The majority of the literature on gardening and horticultural therapy is observational and subjective, and does little to advance understanding of the mechanisms for the therapeutic benefits of gardening. However, a growing number of quantitative studies involving diverse populations and a host of different gardening and horticultural activities have, in general, reported improvements in mental health status of study subjects (Clatworthy et al., 2013). More specifically, studies have reported reductions in anxiety (Lee et al., 2004; Kam and Siu, 2010; Gonzalez et al., 2011b), depression (Gonzalez et al., 2011a; Wilson and Christensen, 2011), negative mood state (Wichrowski et al., 2005; Kam and Siu, 2010; Van Den Berg and Custers, 2011), and perceived stress (Kam and Siu, 2010; Yun and Choi, 2010; Kotozaki et al 2015). As foreseen by Kaplan in her seminal study (1973), interactions with or immersion in nature and natural areas can similarly lead to reductions in anxiety, depression, mood state disorders, and perceived stress, as well as improvements in self-esteem, directed attention, and cognition (Berman et al., 2008; Annerstedt and Wahrborg, 2011; Coon et al., 2011; Keniger et al., 2013). A recent meta-analysis of 25 studies on the health benefits of exposure to nature found consistent evidence for positive changes for feelings of energy, anxiety, anger, fatigue, and sadness (Bowler et al., 2010).

Theories for the Therapeutic Benefits of Gardening and Exposure to Nature and Natural Environments

Throughout human evolution there has been an intimate relationship with nature. One theory posits that directed attention functions in information processing, and its use leads to mental fatigue. Rachel and Stephen Kaplan proposed a framework to explain the apparent restorative benefits of nature on mental health and cognition (Kaplan and Kaplan, 1989) that has become known as Attention Restoration Theory. They postulated that prolonged directed attention requires cognitive or mental effort in order to remain focused on a task and ignore outside distractions. This directed effort leads to mental fatigue. They used the term "fascination" as a central component or attribute of nature as a restorative experience. Fascination or involuntary attention allows individuals to be drawn into nature and “get away”, even if only conceptually, and allows directed attention capacity to be restored. In one form, soft fascination occurs when moderate intensity activities or experiences can focus a person’s attention that allows for the continuance of reflection and cognition. A natural environment is a space where its inherent content and features serve to provide fascination that promotes effortless attention. This, in turn, allows depleted directed attention to be restored (Berman et al., 2008). In this way nature enhances cognitive functions, while reducing negative mood state and promoting positive emotions. Similarly, physiological stress is also seen as being a factor in depleting mental resources that can be restored in a fascination-rich environment (Kaplan, 1995). This, in part, is why nature experiences can be restorative.

Similarly, Ulrich’s Psycho-evolutionary Theory of stress restoration encompasses an integration of aesthetic and affective responses to a natural environment, suggesting that the healing power of nature is, in part, an unconscious, autonomic response to natural elements that can happen without conscious awareness and, most notably, in individuals under physiological stress prior to a nature experience or even to a perceived simulation of nature (Ulrich, 1979; 1981; 1983; Ulrich et al., 1991). Psycho-evolutionary Theory suggests the restorative powers of nature are associated with being in a familiar and safe space. Distinguishing a place as being familiar and safe reduces and relieves feelings of physiological stress and enhances positive affect. This response is thought to be an evolutionary characteristic that favored survival over the course of human evolution. Studies by Ulrich (1979; 1981; 1983) and other studies provided early support for the healing powers of nature as suggested by Ulrich’s Psycho-evolutionary Theory (Ulrich, 1986; Ulrich et al., 1991).

A recent systematic and comprehensive meta-analysis of 31 studies regarding Attention Restoration Theory revealed evidence supporting the theory (Ohly et al., 2016). This meta-analysis utilized study quality indicator tools (Centre for Reviews and Dissemination, 2009; Critical Appraisal Skills Programme, 2013; Effective Public Health Practice Project, 2013) to identify sources of bias and estimate the robustness of the individual studies. Quality scores for the studies ranged from 22.5 to 75% with seven rated as high quality, 22 rated as moderate quality, and two rated as low quality. A number of assessment tools were used in the studies to evaluate attention-related parameters. The Digit Span Forward (DSF) test was used in five studies and the meta-analysis indicated that natural environment exposure groups performed better than controls. The Digit Span Backward (DSB) test was used in 11 studies, and the analysis also indicated that the natural environment exposure groups performed better than the
controls. Five studies, all by the same research group used the Search and Memory Task (SMT) for percentage errors and number of letters searched. There was no difference between the control and nature treatment groups for the percentage error rate, but the control groups performed significantly better than the treatment groups on the number of letters searched. The Trail Making Test B (TMTB) was used in three studies and the analysis showed that the natural environment group performed better than the control group. This meta-analysis while much more robust than most conducted in the area of people and nature and people-plant interactions revealed the need for more studies that utilize the same set of assessment tools that are widely agreed upon to evaluate how nature influences attention and cognitive abilities such as working memory.

Another recent meta-analysis has focused on studies dealing with influence of nature on positive affect which would provide empirical evidence in support of Ulrich’s Psycho-evolutionary Theory (McMahan and Estes, 2015). The Psycho-evolutionary Theory suggests that nature provides a familiar and safe place thereby reducing and relieving feelings of stress and improving positive affect. This meta-analysis included 32 studies. Despite there being considerable heterogeneity in the experimental designs and methods of the individual studies, the findings of the meta-analysis suggest that exposure to natural environments did result in moderate improvements in positive affect along with a smaller reduction in negative affect relative to control groups. McMahan and Estes (2015) also examined whether there was a difference in responses to actual nature experience or simulated nature such as viewing photographs of nature. They found larger effect sizes in response to real nature as compared to that of simulations of nature. Therefore, while viewing simulations of nature can improve positive affect, actual nature experience appears to have a greater ability to improve positive affect. These overall results can be viewed as support for Ulrich’s Psycho-evolutionary Theory for the restorative powers of nature experiences.

**Behavioral and Cognitive Benefits of Gardening**

Behavioral and cognitive effects of LDSM conditions based on isolated, confined and extreme (ICE) analog environments and psychological assessments of astronauts on longer duration Space Shuttle flights and missions to the various space stations including Salyut, Mir and ISS have been informative, and demonstrate increased likelihood of mental health disturbances (Sandal et al., 2006; Paulus et al., 2009). Given the goal of reaching Mars, psychological issues are expected to be exacerbated with the decrease in ground-based therapeutic interventions that are now possible in current low Earth orbit missions. Therefore, space farming or gardening may offer a treatment modality that reduces the decline of crew mental health and well-being. A rigorous critical assessment of the evidence-based research on gardening as a mental health intervention was conducted by Clatworthy and colleagues for the years 2003-2013 (Clatworthy et al., 2013). From a list of 156 references produced by systematic search, just ten studies met four standards: 1, providing an empirical evaluation of an intervention involving active gardening; 2, adult participants experiencing functional mental health difficulties; 3, published in a peer-reviewed journal; and 4, written in English (Son et al., 2004; Stepney and Davis, 2004; Parr, 2007; Rappe et al., 2008; Gonzalez et al., 2009; 2010; 2011a; b; Kam and Siu, 2010; Parkinson et al., 2011). Based on quantitative psychometric assessments, seven of the studies reported statistically significant reductions in depression, four showed reductions in anxiety, two found increased attentional capacity, and one reported increased self-esteem. Qualitatively, three studies found reductions in stress and improved mood, and two recorded improved social skills. An earlier critical assessment of studies on the benefits from gardening for adults with mental health difficulties by Sempik and colleagues (2003) identified as few as five studies that were experimentally sound. As a further example, a search for randomized controlled trials involving horticultural therapy by Kamioka and colleagues (2014) returned only four studies. Two of the studies reported improvements in depression symptomatology (Kim et al., 2003; Kam and Siu, 2010). A more recent series of studies by Kotozaki and colleagues (Kotozaki, 2013a; b; 2014a; b; c; Kotozaki et al., 2015) focused on women suffering from PTSD from the Great East Japan Earthquake of 2011 have provided additional empirical evidence for the benefits of gardening or horticultural therapy. Taken together, these studies have shown gardening-based experimentally controlled horticultural therapy interventions result in statistically significant improvements in positive affect, total mood disturbance, quality of life as well as reductions in clinician-administered PTSD Scale scores and salivary cortisol levels. Further conclusions drawn from a number of retrospective studies and reviews concerning the mental health benefits of gardening identify the paucity of sound empirical evidence as a prevailing problem, and underlines the need for more high quality research.
Social Benefits of Plants

With the associated challenges of long-duration spaceflight, including isolated, confined and extreme environmental conditions, astronauts are at risk for interpersonal issues with their flight crew members and ground-based control. Other factors affecting cohesion of crew members are faulty leadership and cultural barriers (Kanas et al., 2001; Bates et al., 2009). Such interpersonal conflicts could lead to a number of undesirable group dynamics such as decreased trust, cooperation, productivity and safety. Furthermore, interpersonal conflicts could lead to a number of negative behaviors associated with sleep, attention, anxiety, depression, substance use, stress, and rumination. Interacting with plants and accessing plant-rich environments have been correlated to enhanced social integration, group cohesion and social functioning (Cho and Mattson, 2004; Son et al., 2004; Gonzalez et al., 2011b). In one study, inner-city participants reported an enhanced sense of safety and preference associated with more green space (Kuo et al., 1998). In a study conducted by Kuo and Sullivan (2001), increased plant density was correlated with decreased crime rates, violence, aggressiveness and residents’ fear in an inner-city community. Qualitative studies indicate community garden efforts can encourage positive social behaviors (Waliczek et al., 1996) and promote cultural and/or racial social interactions (Shinew et al., 2004; Wakefield et al., 2007). Taken together, these studies point to horticultural activities as a way to build social union and dismantle social tensions; benefits which could be especially valuable to flight crews under ICE conditions during LDSMs.

Psychological Benefits of Indoor Plants

Plants are commonplace in homes, the workplace, and public indoor spaces like lobbies, atriums, waiting rooms, and shopping malls, but plants have commonly been kept in their own isolated and confined boxes during spaceflight. In some cases, flight crews have been able to more closely interact with plants and have been able to cultivate and care for them. Plants are brought indoors for many different reasons, including enjoyment, aesthetics, interiorscaping, and for health-related benefits. For decades, indoor plants have been touted for their health and therapeutic benefits. A critical analysis of the peer-reviewed, published experimental literature on the behavioral effects including cognition, affect, and physiology that indoor plants passively provide to occupants was conducted by Bringslimark and colleagues (2009). Following a systematic literature search, 21 studies were selected for analysis. Overall, the results for psychological benefits were found to be mixed. Reasons for different outcomes among studies included experimental diversity and lack of standard methods in settings, experimental design, treatments, number and types of plants, exposure durations, types of samples, and measurement methods, small magnitude of effects, and lack of sufficient power to detect treatment effects. The most consistent findings of benefit were reduced pain and anxiety following surgery (Park et al., 2004; Park and Mattson, 2008; 2009), and higher pain tolerance (Lohr and Pearson-Mims, 2000).

Influence of Nature and Gardening on Patterns of Brain Activation

Studies are emerging that couple neuroimaging with nature experiences or gardening for therapeutic purposes in an effort to link changes in behavioral health with patterns of brain activation. A recent study found that images of the sky produced activations in the same regions of the brain as other positive stimuli (Pati et al., 2014). Two studies looked at the patterns of brain activation upon viewing images of landscapes compared against neutral versus ugly stimuli, or outdoor versus indoor images (Kawabata and Zeki, 2004; Henderson et al., 2007). Both studies reported differential activation patterns suggesting that the brain responds differently to outdoor and natural landscapes. The first study to examine changes in the patterns of brain activation resulting from a horticultural therapy intervention was conducted on a group of five individuals recovering from cerebrovascular disease (Mizuno-Matsumoto et al., 2008). Unfortunately, the study is highly suspect due to the small sample size and overall weak experimental design. Two other studies published in 2015 offer a stronger connection of neurological changes and patterns of activation with gardening and nature. Following an 8-week horticultural therapy intervention, women suffering from PTSD resulting from the 2011 Earthquake in Japan had increased regional gray matter volume of the left subgenual anterior cingulate cortex and left superior frontal gyrus compared to the control groups that received an 8-week educational intervention (Kotokazi et al., 2015). These two regions of the brain are associated with mood disorders and depression (Drevets et al., 2008), and cognitive functions, particularly working memory (Du Boisgueheneuc et al., 2006). Another study
contrasting the levels of rumination before and after walking through a nature or urban setting for 90 minutes measured reduced rumination for the participants taking the nature walk, but no change for those taking the urban walk. Using arterial spin labeling magnetic resonance imaging, cerebral blood flow was quantified. Regional blood flow decreased in the subgenual prefrontal cortex for nature walk participants only, suggesting reduced neural activity. This region of the brain has been linked to increased activation associated with higher levels of rumination. Participants taking the urban walk did not show a reduction of cerebral blood flow or decreases in rumination (Bratman et al., 2015). More scholarly work in the area of brain activation is necessary to unveil a clearer understanding of the linkages between these patterns of brain activity, behavioral health, and nature and gardening.

**Anecdotes from Astronauts on People-Plant Interactions in Space**

*“Pleasure for one hour, a bottle of wine. Pleasure for one year, a marriage; but pleasure for a lifetime, a garden.”*  
Chinese Proverb

Growing plants in space could provide salads and other foods for future space crews, but they also may bring other psychological and biological benefits. Perhaps the first indication of the psychological impact of growing plants in space was expressed by Cosmonaut Valentin Lebedev (1990) in his diary during spaceflight where he wrote: “Our “farms” in the Oazis, Fiton, and Svetoblock, where we cultivated plants, are empty now.” Lebedev later recorded that: “During a TV broadcast we admitted that we feel sad and uncomfortable without our garden and without our dear plants. It was such a pleasure to take care of them. Man probably has a need to take care of things and without those things feels empty.” Similarly, when she first saw the growing soybeans in the Advanced Astroculture™ (ADVASC) Experiment hardware on the ISS (Figure 2), Peggy Whitson, an Iowa native, reported in an e-mail letter home to family and friends: “It was surprising to me how great 6 soybean plants looked.” She also wrote: “I guess seeing something green for the first time in a month and a half had a real effect. From a psychological perspective, I think it’s interesting that the reaction was as dramatic as it was.” Whitson went on to write: “guess if we go to Mars, we need a garden!” Astronaut Don Pettit affectionately described his interaction with a zucchini plant. In one of his blogs, taking on the persona of the zucchini, Pettit wrote about his experience with the zucchini: “Apparently he takes pleasure in my earthy green smell. There is nothing like the smell of living green in this forest of engineered machinery.” More recently Scott Kelly’s Tweet on January 16, 2016 of the: “First ever flower grown in space makes its debut!” was picked up by the media and generated worldwide interest. Kelly took over care of zinnia plants that were being grown by Astronaut Kjell Lindren for an experiment in the Veggie plant growth platform on the ISS (Figure 3). A control cohort of plants was also being grown on Earth for comparison. In fact, it was Kelly’s care that salvaged the experiment and enabled some of the plants to overcome a fungal growth problem and develop flowers. In an interview with NASA, Kelly explained: “I think we’ve learned a lot about doing this kind of experiment. We’re being farmers in space,” Kelly declared: “I was extra motivated to bring the plants back to life. I’m going to harvest them on Valentine’s Day.” (NASA Flowering Zinnias, http://www.nasa.gov/feature/flowering-zinnias-on-space-station-set-stage-for-deep-space-food-crop-research). One can speculate why one zinnia flower on the ISS would be so interesting and such a big deal to so many people? A Google search of “first flower in space” returned just under 80 million hits (searched November 25, 2016). When taken together, the expressed enthusiasm by astronauts and cosmonauts for seeing and growing plants in space provide a compelling justification for quantitative research studies measuring the impacts that plants have on crew mental health and well-being under spaceflight conditions. It is appreciated that in addition to recycling carbon and oxygen, growing plants in the easily accessible Veggie is recognized as an opportunity for astronauts to receive the psychological benefits of growing and caring for plants on the ISS (Vessel and Russo, 2015).

The zinnia flower experiment is not the first to attempt to have flowers on an orbital station. The Malachite device plant growth system on Salyut 6 was used for an experiment with the purpose of growing ornamental plants. The idea in this experiment was to provide psychological benefits for the cosmonauts on the space station. The plant growth system had four boxes with a water supply and lighting to support plant life. Orchids were chosen to be sent into space bearing flower blossoms (Neichitailo and Mashinski, 1993, Porterfield

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1 Scott Kelly’s Tweet was incorrect as a number of different plants had flowered in space on several occasions over the previous 30 years of manned spaceflight.
Figure 2. Flight engineer Peggy Whitson was pleased to show soybean plants growing in the Advanced Astroculture™ (ADVASC) Experiment hardware on the ISS on July 10, 2002. The hardware provided precise control of light, temperature, fluid nutrient delivery, relative humidity, carbon dioxide (CO2) and ethylene concentrations. An agricultural seed company grew the soybeans in the ADVASC hardware to determine if soybean plants could go from seed to seed in a microgravity environment. Secondary objectives included determination of the chemical composition of the seeds grown in space and whether microgravity had an impact on the plant growth cycle. Image catalogued by Marshall Space Flight Center of the United States National Aeronautics and Space Administration (NASA) Photo ID: MSFC-75-SA-4105-2C. Image credit: NASA https://mix.msfc.nasa.gov/abstracts.php?p=2393

Figure 3. Zinnia plants in flower in the Veggie plant growth system onboard the International Space Station on January 16, 2016. Plants were grown from November 16, 2016 to the date of the photograph by astronauts Kjell Lindgren and Scott Kelly. Growing zinnias on the ISS provided an opportunity for the astronauts to practice gardening in space. The first flowers grown from seed in space occurred previously on Mir, on Salyut-6 in 1982. Russian and American scientists have been conducting plant research in space since the late 1970’s. Image catalogued by Johnson Space Center of the United States National Aeronautics and Space Administration (NASA) Photo ID: ISS046-E-009029. Image credit: NASA https://upload.wikimedia.org/wikipedia/commons/f/fd/ISS-46_Zinnia_flowers_in_the_Veggie_facility_%283%29.jpg
et al., 2003). Cosmonauts Popov and Ryumin in 1980 found that the orchids grew normally for 177 days but they didn't flower. Several in-bloom orchids that were carried to the space station quickly faded and lost all their blossoms within 23 days of arrival in orbit. Orchids were chosen for the experiment, because they don't always grow upwards on Earth. While these anecdotes do not provide direct experimental evidence in support of the psychological benefits of growing plants in space, they do show the affective responses and high level of interest by the astronauts associated with having greenery on board space vessels.

Gaps and Countermeasures

Future studies involving the analysis of plant-mediated psychosocial factors could address NASA Human Research Program gaps to identify promoters and validate model countermeasures that will help to sustain individual and group psychosocial health and cognitive performance during LDSMs. At this time, there is great need for more research in all areas of people-plant interactions to better define treatment effect size responses and understand the true impacts that nature and plants have on human well-being. Interestingly, research implementing plants in isolated and closed environments that are characteristic of LDSMs has the potential to generate extremely important empirical evidence that presently does not exist in the extant literature. Results from such studies could lead to more complete conclusions on the beneficial effects of people-plant interactions in ICE environments, specifically related to psychosocial health, cognitive performance, and group cohesion. A current weakness in all studies of the benefits of people-plant interactions, especially those surrounding the Biophilia Hypothesis context, is the background influence of the presence of plants in the daily life of study participants. Moreover, there is not a good understanding of how long the benefits of a nature experience or person-plant interaction persist. Removal of this background or residual influence could amplify and reveal the magnitude of treatment effect size emanating from people-plant interactions. At the present time, analog LDSM ICE environments on Earth could be used to formally test the true impact of being in the company of, growing, and enjoying the rewards plants can provide. This could be accomplished in a true experimental design with and without plants. It offers the opportunity to identify a potentially effective, accessible, and non-pharmacological therapeutic modality to treat adverse behavioral conditions and psychiatric disorders. Perhaps more importantly, projects involving plant-mediated therapeutic modalities will contribute to the identification of an effective method for modifying the habitat/vehicle environment, specifically during LDSMs, to mitigate decrement of psychological and behavioral health due to environmental stressors stemming from prolonged ICE conditions. This could be accomplished using assessment instruments and tests that are widely recognized standards used in the fields of psychology and neuroscience.

Conclusion

As humankind ventures further away from Earth, our food and favorite plants will be carried along on the journeys much further from their Vavilovian centers of origin than ever before. Taken together, there is a limited, but a sufficient body of empirical evidence to suggest that nature and plants, particularly active interactions with plants through farming and gardening, offer behavioral health and cognitive function therapeutic benefits. While there is evidence for these benefits in ambient Earth-bound environments, we are not aware of a single study that demonstrates whether or not the therapeutic benefits would carry over into a spaceflight environment disconnected from the natural sensory stimulation and input provided by plants. Determination of the magnitude of treatment size effects of plants on neurocognitive functions is a step toward establishing space farming and active engagement with plants in space as a potentially effective non-pharmacological countermeasure to the anticipated decrement of behavioral health and performance during LDSMs. It is clear that more research is necessary to arrive at a better understanding of the mechanisms involved in people-plant interactions on Earth and in space.

Acknowledgements: The authors would like to thank the Department of Environmental Horticulture for support for this work and the Gene and Barbara Batson Endowed Nursery Fund for support of the graduate assistantship to R. Odeh. Both authors contributed to the writing of this paper.

Conflict of interest: Authors declare nothing to disclose.
References


Berman, M., Kross, E., Kranp, M., Askren, M., Burson, A., Deldin, P., et al., Interacting with nature improves cognition and affect for individuals with depression, J. Affect. Disord., 2012, 140, 300-305


Butterfield, B., The Impact of Home and Community Gardening in America, National Gardening Association, pp. 1-17, 2009


Centre for Reviews and Dissemination, Systematic reviews: CRD’s guidance for undertaking reviews in health care, York, UK, 2009


Coon, J., Boddy, K., Stein, K., Whear, R., Barton, J., Depledge, M., Does Participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. Environ. Sci. Technol., 2011, 45, 1761-1772


Jo, H., Rodiek, S., Fuji, E., Miyazaki, Y., Park, B., Ann, S., Psychological and psychological response to floral scent, Hortscience, 2013, 48, 82-88

Kam, M., Siu, A., Evaluation of a horticultural activity programme for persons with psychiatric illness, Hong Kong J. Occup. Ther., 2010, 20, 80-86


Rush, B. Medical Inquiries and Observations, Upon the Diseases of the Mind, Kimber and Richardson, Philadelphia, 1812


Stepney, P., Davis, P., Mental health, social inclusion and the green agenda: An evaluation of a land based rehabilitation project designed to promote occupational access and inclusion of service users in North Somerset, UK, Soc. Work Health Care, 2004, 39, 375-397


Ulrich R.S., Human responses to vegetation and landscapes, Landscape Urban Plan., 1986, 13, 29-44


Van Den Berg, A.E., Custers, M.H.G., Gardening promotes neuroendocrine and affective restoration from stress, J. Health Psychol., 2011, 16, 3-11


Vavilov, N.I., The Phytogeographical Basis for Plant Breeding, in Theoretical Basis for Plant Breeding, Vol. I., Pgs 17-75, Moscow, USSR [in Russian, English Translation], 1935


Wilson, J., Christensen, K., The relationship between gardening and depression among individuals with disabilities, J. Ther. Hort., 2011, 21, 28-41


Zeven, A.C., Zhukovsky, V.M., Dictionary of Cultivated Plants and Their Centres of Diversity: Excluding Ornaments, Forest Trees and Lower Plants, Centre for Agricultural Publishing and Documentation, Wageningen, 1975